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FOREWORD

MAN'S ROLE IN DYNA-SOAR FLIGHT

FOR

BIOASTRONAUTICS PANEL OF SCIENTIFIC ADVISORY BOARD

ARTHUR MURRAY

MANAGER — HYPERSONIC CREW INTEGRATION

SEATTLE — FEBRUARY 21, 1962

The information in this document represents the philosophy of The Boeing Company on the usefulness of man in general and a pilot in particular in the Dyna-Soar system. This consistent piloted aspect of the orbital glider has been one of the basic and firm Air Force ground rules on which the project has been conducted under the direction of the Dyna-Soar System Program Office of the Aeronautical Systems Division. The use of man in recent research flight projects, and his inclusion in the very early planning stages of Dyna-Soar could be, and was, predicated mainly on tradition, intuition, and supposition. The principal supposition required was as to the functional value of piloted versus automatic operation in an orbital system. There is a growing body of opinion, which was evident at the time of Commander Shepherd's and Captain V. Grissom's Mercury/Redstone flights, and which tended to solidify upon Colonel John Glenn's successful Mercury/Atlas orbital flight, to the effect that the requirement for man in space has been adequately validated especially in those cases where a degree of flexibility is required.

This presentation accepts man as a required and validated element of a flexible return from orbit system which will maneuver to a selected landing point. This material does not justify "why man in space?" It does show how he is used by the Dyna-Soar designer to simplify systems, reduce costs, or improve operational research reliability.

The effect of the concrete experiences encountered on missile projects (Regulus and Bomarc), supersonic aircraft (F8U, F100), hypersonic aircraft (X-1, X-2

FOREWORD (Cont)

and X-15), and Mercury experience are projected to the planned Dyna-Soar mission. Mr. Murray's past experience as a research rocket aircraft pilot and present responsibility for management of crew integration were used to select areas of emphasis.

Due to the personal interest and concern of Mr. A. M. Johnston, Program Manager, in the integration of the crew to Dyna-Soar, project engineering and staff effort in this area is so widespread that individual acknowledgement of all contributors would be difficult. However, recognition of the inputs of the following Boeing Aero-Space Division personnel is made:

Mr. N. L. Krisberg, Chief, Technical Staff — General technical philosophy

Dr. Y. A. Yoler, Staff Engineering — Space Projects — Staff philosophy

Mr. R. R. Rotelli, Assistant Senior Project Engineer — Critique of project inputs

Dr. R. Y. Walker, Staff Assistant Human Engineering — Time line analysis

Mr. L. R. Mason, Dyna-Soar Flight Technology Unit Chief, Mr. G. Dragseth, Air Vehicle Stability and Control Supervisor and Mr. A. H. Lee, Dyna-Soar Flight Control Supervisor — Stability characteristics, flight control task, glider/booster simulation

Mr. R. G. Christensen, Section Head, System PD and Evaluation Section — Manned booster consideration

Mr. T. K. Jones, Unit Chief, Reliability and Safety Unit — Safety implications

Mr. S. Howland, Acting Supervisor, Reliability Requirements and Status Assessment Group — Safety and reliability considerations

Mr. T. R. Waddleton, Supervisor, Space and Research Systems — Use of man during test

Mr. F. E. Woods, Staff Engineer, Test Technology Staff — Bomarc and Minuteman experience

Mr. L. A. Perro, Supervisor, Test Control Equipment Design — Role of pilot during countdown

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FOREWORD (Cont)

Acknowledgment is made of the contributions on the following individuals in the areas of missile and high-performance jet and rocket aircraft projects.

Mr. Paul F. Bikle, Director NASA High Speed Flight Station, Edwards, Calif.

—Research aircraft philosophy

Mr. DeBeeler, Deputy Director NASA High Speed Flight Station, Edwards, Calif.

—Research aircraft philosophy

Messrs. J. Walker, J. B. McKay, and V. Horton, NASA High Speed Flight Station — X-15 and Jet/Rocket aircraft experience

Messrs. G. Matranga, J. Gibbons, and V. Horton, NASA High Speed Flight Station — X-15 and Jet/Rocket aircraft experience

Mr. D. G. Starkey, Chance Vought Aircraft Corporation — Regulus, F8U experience

Mr. J. Wesesky, Flight Test Engineering Section AFFTC, Edwards, Calif. — History of X-15 flights

Mr. R. Nagle, Flight Test Engineering Section AFFTC, Edwards, Calif. — History of X-15 flights

The information presented is current to the date of February 21, 1962.

1.0 INTRODUCTION

1.1 Purpose

This document records information conveyed during a briefing prepared for and given to the Bioastronautics Panel of the Scientific Advisory Board on the subject of the use of man in Dyna-Soar.

1.2 Scope

The information herein delineates the conceptual integration of man (as a pilot) to Dyna-Soar. Material consists of reductions of the charts used during the meeting. The charts were constructed to summarize internal studies and discussions of project design and staff support engineering, reliability, integration, and bioastronautics groups which contributed to the evolution of the present Dyna-Soar configuration.

The principal points elaborated upon over and above those quoted by the charts are highlighted and detailed on the individual charts.

In accord with discussions with panel members, the related background data from which these comments were evolved, along with a complete definition of assumptions made, are documented.

1.3 Applicability

The material represents philosophy, design concepts, and a glider-booster configuration as it existed at the time of the Seattle meeting. It is not expected that the philosophy and concept will change materially. Data emanating from related aircraft/missile projects and the glider design itself is changing daily. It should be noted that it is not therefore intended to keep the document updated particularly in regard to those items dependent upon detailed glider design data.

1.4 Authority

The briefing of the Scientific Advisory Board was accomplished as delineated by United States Air Force teletype.

The gathering of the background and supporting data has been accomplished in response to Scientific Advisory Board letter of April 23, 1962 to A. M. Johnston from L. D. Carlson (Chairman).

1.5 Participation

The attendees of the Bioastronautics Panel meeting, the Boeing participants, and the agenda are shown in the succeeding section.

AGENDA
AEROMEDICAL AND BIOSCIENCES PANEL
SCIENTIFIC ADVISORY BOARD

Visit to Boeing — February 21, 1962

Wednesday, February 21, 1962

9:00	Introduction to Boeing	N. L. Krisberg
9:20	Dyna-Soar Program and Progress Film	
10:35	Refreshment Break	
10:50	Man's Role and Operation in Dyna-Soar	A. Murray
11:00	Applications of Bioastronautics to Dyna-Soar System	R. Y. Walker
11:15	Engineering Design Considerations for a Manned System such as Dyna-Soar	
	(a) Cockpit design, displays, ejection seat, survival equipment, etc.	G. Graham
	(b) Vehicle environment system	R. Olsen
11:45	Dyna-Soar Mockup Tour	B. Hamlin R. Shepherd
	Simulator Operation	A. Murray E. Kangas
12:45	Transportation to BSRL	F. W. Zuppe
1:00	Luncheon — BSRL	G. Hollingsworth
1:55	Return to 2.01 Building	F. W. Zuppe
2:00	Bioastronautics in General	R. H. Lowry
2:30	Tour of Bioastronautics Laboratories	R. H. Lowry

MEMBERS, CONSULTANTS, AND OBSERVERS

Professor L. D. Carlson (Chairman)	Dr. Jessee Orlansky
Dr. R. F. Buchan	Col. Carl Houghton
Dr. C. M. McDonnell	Col. Clyde Gasser
Dr. Frank Princi	Mr. Donald Almy
Dr. B. M. Wagner	Dr. A. W. Hetherington
Dr. Stuart Bondurant	Dr. Edwin Vail
Dr. K. S. Lion	Sqd. Leader John C. Henry
Dr. John Marbarger	Maj. Arthur W. Kidder, Jr.
Dr. L. M. Petterson	Mr. E. O. Berdahl
Brig. Gen. Don Flinkinger	Capt. H. L. Bitter
Mr. C. L. Arnold	Col. Randel

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6

Dyna-
Soar

R & D PROGRAM OBJECTIVES

- DEMONSTRATE PILOTED MANEUVERING RE-ENTRY FROM ORBIT WITH CONVENTIONAL GLIDE LANDING AT PRECISE LANDING SITE
- GATHER RESEARCH DATA FOR ADVANCED DESIGN FOR CONTROLLED LIFTING RE-ENTRY FROM ORBITAL FLIGHT
- ✓ ● EXPLORE FULL POTENTIAL OF PILOT

DS-002-10181

On the subject of man's role in Dyna-Soar we find that man has always had a role in space. This has been true since the inception of Dr. Saenger's pre-World War II thinking on space flight and the trans-Atlantic skip bomber proposal to the German General Staff. It has been true of 1950-1957 United States studies such as Bomi, Brass Bell, etc. It was true of the 1957 Industry Competitive Studies that led to Dyna-Soar. In Dyna-Soar, the role of man results from the objectives of the project.

The details of these objectives may be examined in the light of contractual statements such as:

Program Objectives
Dyna-Soar Approach
System Design Objectives
Test System Objectives
System Design Requirements
and Test System Requirements

These are included as Appendix A.



FEATURES OF DYNA-SOAR PROGRAM

- UNIQUE FEATURE – RETURN MEN AND MATERIALS FROM SPACE TO AIRPORT OF PILOT'S CHOICE. ✓
- ONLY AIR FORCE MAN IN SPACE PROGRAM
- ONLY PILOTED MANEUVERABLE RE-ENTRY PROGRAM IN FREE WORLD z
- PASSIVE RADIATION-COOLED STRUCTURE — REUSEABLE

These features are unique to the Dyna-Soar Program. They are incorporated in the design in response to contractual statements and are being translated into actual hardware.



MANS ROLE IN DYNA-SOAR RESEARCH SYSTEM

- DECISION-MAKING CAPABILITY
- COMMAND CONTROL CAPABILITY
- DETERMINATION OF VEHICLE AND PAYLOAD STATUS
- POST-LAUNCH CHANGES IN MISSION PLAN
- PAYLOAD REDUNDANCY
- MISSION DATA REDUNDANCY
- MISSION DATA AUGUMENTATION
- RECOVERY OF ON-BOARD PAYLOAD DATA
- ACCOMPLISHMENT OF MISSION DETAILS
- SUBSYSTEM SIMPLIFICATION
- EARLY MISSION TERMINATION & RECOVERY

DS-022-103

See Appendix B for details of the role described by these 11 points.

Dyna-
Soar

PILOTS ROLE IN DYNA-SOAR

- PILOT COMPLEMENTS CAPABILITY OF LIFTING
AND MANEUVERABLE GLIDER
 - CORRIDOR EXPLORATION -?
 - LIMITING FUNCTIONS
 - ALTER TEST PLANS
 - LANDING
- PILOT AUGMENTS CONCEPTS OF REDUNDANCY AND
BACKUP SYSTEMS THROUGH
 - OBSERVATION
 - EVALUATION
 - JUDGEMENT
 - ACTION!
- PILOT TESTS MAN'S VALUE IN POSSIBLE FUTURE
SYSTEMS

05-052-107

These elements are significant to the use of a man in Dyna-Soar.

Dyna-
Soar**EFFECT OF PILOT & REDUNDANCE****X-15 MISSION SUCCESS-FREE-FLIGHT PHASE**

40 FLIGHTS	BASED ON ANALYSIS OF FLIGHT DATA			ACTUAL
	<u>NO PILOT SINGLE SYSTEM</u>	<u>PILOT & SINGLE SYSTEM</u>	<u>NO PILOT DUAL SYSTEM</u>	<u>PILOT & DUAL SYSTEM</u>
MISSION SUCCESS	21	23	23	33
MISSION PARTIAL SUCCESS	0	0	0	1*
ALTERNATE MISSIONS SUCCESS	0	3	0	6
GLIDER RECOVERY ONLY	1	2	1	0
TOTAL	22	28	24	40
AIRPLANE LOSSES	18	12	16	0

* 1 FLIGHT RESULTED IN DAMAGE (REPAIRED) ON LANDING

The subject of how man should be used in space and space-type aircraft has been of continuing interest to the Government and to industry. The Air Force Flight Test Center has examined the results of a series of 40 X-15 flights. An explanation of the ground rules under which the study was conducted is covered by AFFTC letter to The Boeing Company (subject: "Redundant System and Pilot-in-the-Loop Aspects of all X-15 Flights") and is included as Appendix C.

The individual detailed data from which the study was made is included verbatim as Appendix H.

The results of the study have been summarized in the chart above.

It is significant that, as indicated by the column on the far right, no piloted airplanes have been lost. Reading toward the left along the column of airplane losses we may see the increasingly degraded effect on a research program from elimination of the pilot and dual or emergency systems.

It can also be seen that neither the pilot nor dual systems alone are sufficient to eliminate these potential losses. The best results come from use of a pilot with adequate dual or emergency systems with which to work.

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EFFECT OF PILOT & REDUNDANCY

X-15 - PRELAUNCH PHASE

(ANALOGOUS TO FIRST-STAGE BOOST -
EXCEPT RECOVERABLE & RECALLABLE)

71 LAUNCH ATTEMPTS	BASED ON ANALYSIS OF FLIGHT DATA			ACTUAL
	NO PILOT SINGLE SYSTEM	PILOT & SINGLE SYSTEM	NO PILOT DUAL SYSTEM	PILOT & DUAL SYSTEM
SUCCESSFUL LAUNCHES FROM 71 LAUNCH ATTEMPTS	25	29	25	40

DS-027-191

Such a great amount of difficulty was encountered in getting the X-15 to the point of the 40 launches that it was decided to examine the prelaunch phase.

The analysis indicated that an appreciable improvement in mission success resulted from use of a pilot and dual systems even under the relatively well controlled phase prior to launch.



DYNA-SOAR FLIGHT CONTROL SYSTEM

MODES OF OPERATION

- MANUAL-DIRECT
- MANUAL-AUGMENTED (FIXED GAIN)
- MANUAL-AUGMENTED (ADAPTIVE)
- AUTOMATIC

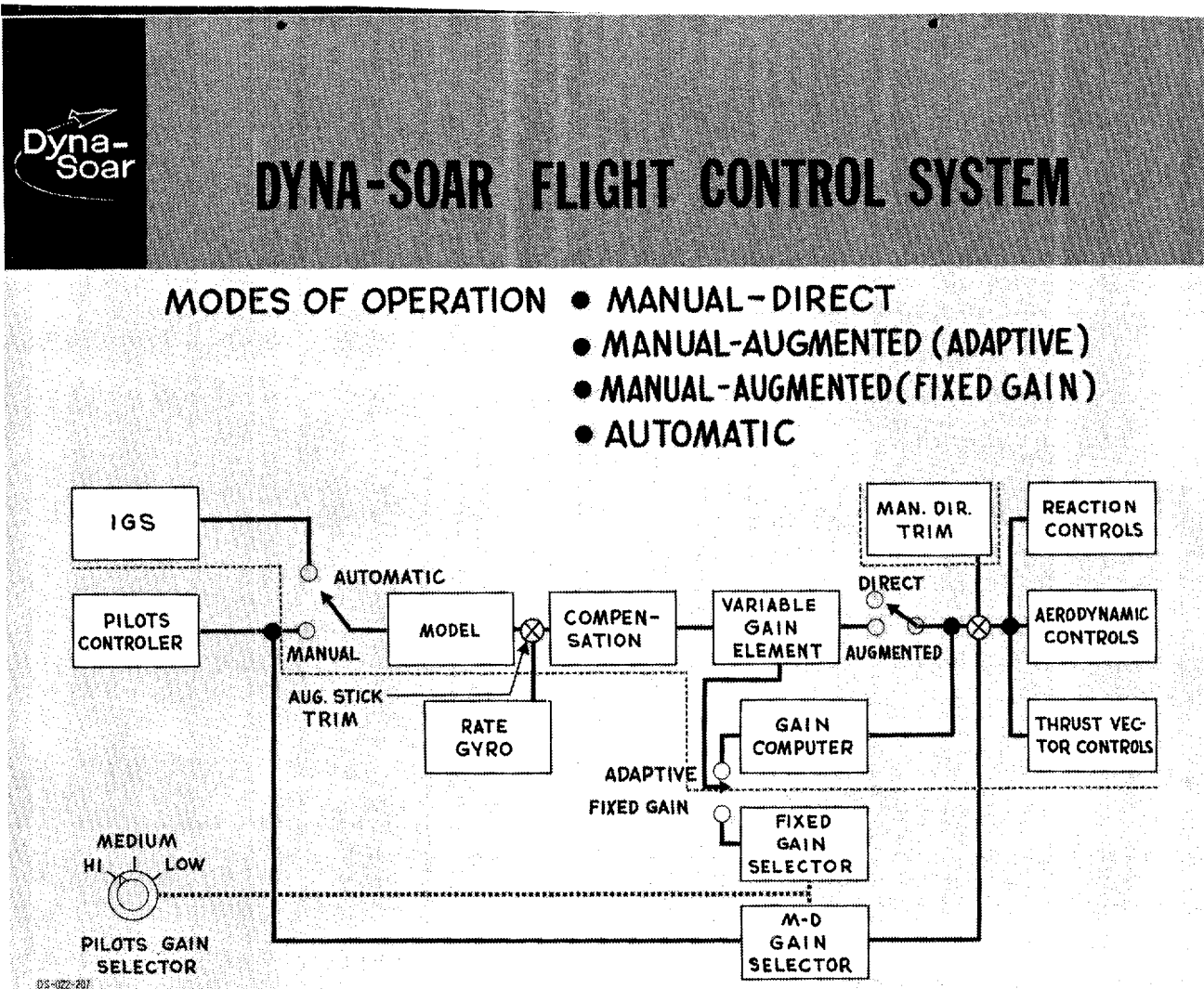
Manual Direct — In the manual direct mode, pilot inputs are translated directly into control surface movement through the electrical-hydraulic flight control components.

This is the electro-hydraulic equivalent of WWI and II cable and pulley systems with the inclusion of a ratio changer. In this mode, there is no augmentation and the pilot alone copes with the natural stability of the glider, modulates excursions, and applies a human "gain" based on his background of flight experience.

Manual Augmented (Fixed Gain) — In this mode, pilot inputs are transmitted electrically and hydraulically to the flight control surfaces after being modulated by a pilot-selected and pre-established amount of fixed gain from the adaptive system. Simultaneously, and irrespective of pilot inputs, the basic airframe aerodynamic stability characteristics are improved by the augmentation feature that reduces short period oscillations.

Manual Augmented (Adaptive Gain) — Pilot inputs in this mode are again transmitted electrically and hydraulically to the control surfaces and the glider control surface motions and resulting maneuvers are modulated by an adaptive system. By continuously sensing its output against its input, the adaptive system varies its own gain to cope with the considerable change in stability of the glider. This change occurs when a lifting body undergoes the transition from orbital velocity to conventional landing speeds. Concurrently, the augmentation effect of the system attenuates short-period glider oscillations.

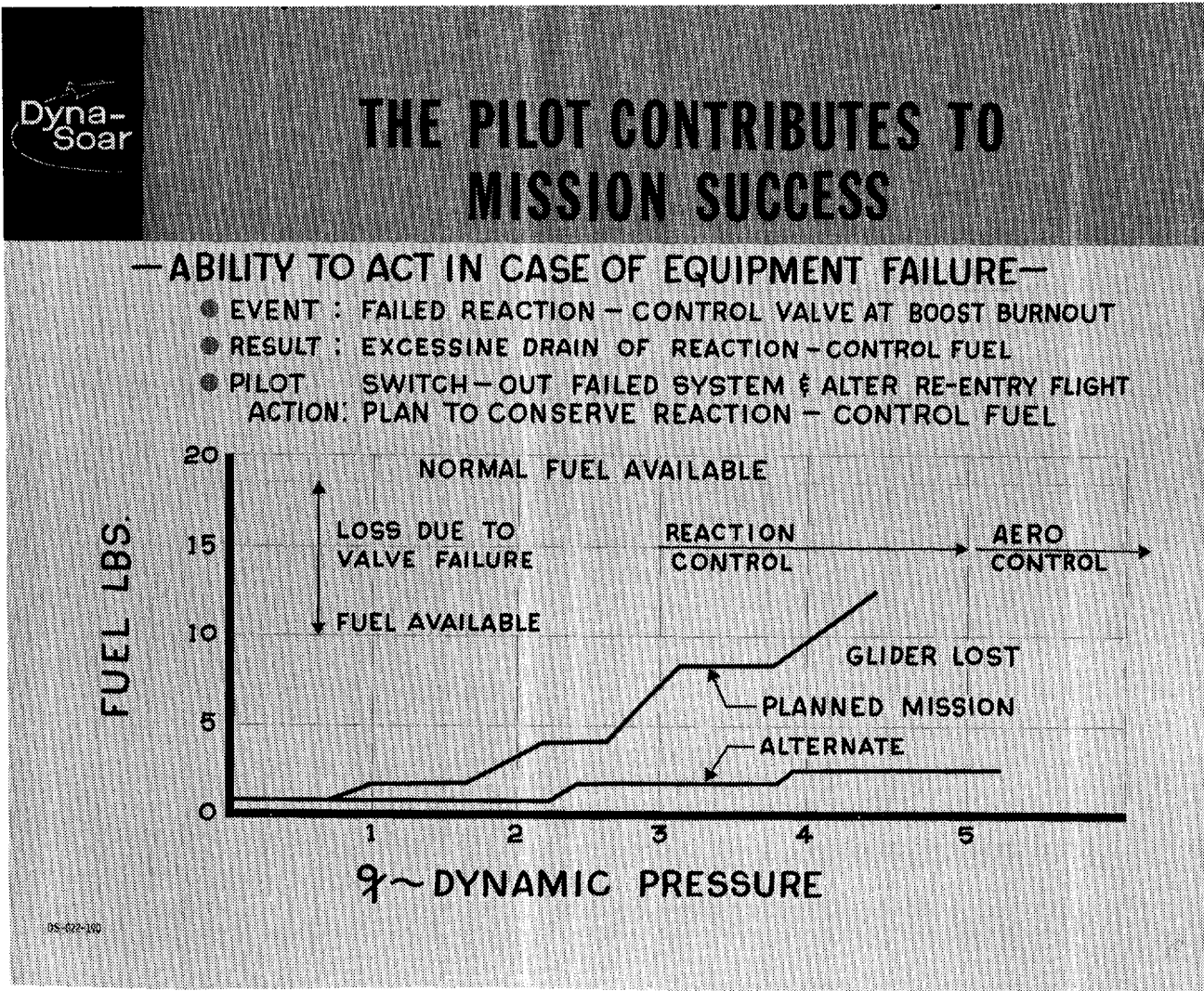
Automatic — In this mode, the pilot makes no inputs whatsoever and the adaptive control system of the glider responds automatically to the signals generated by the Inertial Guidance System only.



The concept of these four optional modes of operation available to the pilot may be visualized by examination of the major elements of equipment that make up the flight control system indicated above.

The equipment above the dotted line, from the Inertial Guidance System (IGS) through to the reaction/aerodynamic and vector controls, is essentially a conventional missile-type system and yields automatic control. The elements added below the line, and the manual direct trim, yield the three additional modes, each of which utilize the pilot-in-the-loop.

These modes give the pilot the wherewithal to carry out the actions dictated by his judgement.



One of the instances where use is made of the pilot is illustrated by a Boeing simulator study in which runs were accomplished assuming a failed reaction control valve.

For a "q" or dynamic pressure of 0 psf to 5 psf, reaction control is required to recover the glider (and pilot). From 5 psf to 10 psf, a situation exists where, on occasion, a re-entry can be safely made. Above 10 psf, aerodynamic pressure is usually adequate.

Note that with a valve failure at boost burnout (less than 1 psf "q"), the glider would be lost if on automatic flight. In these simulations the pilot switched to an alternate mission that would have used considerably less fuel and saved the glider.

Dyna-
Soar

EXAMPLE OF SPECIFIC PILOT ACTION

EVENT:

- UNEXPECTED EXPENDITURE OF ENERGY IN EXIT OR RE-ENTRY

AUTO. SYSTEM ACTION:

- CONTINUE TO HEAD FOR ORIGINAL DESTINATION AND NOT REACH IT.

PILOT ACTION:

- DETERMINE THAT DESTINATION IS INACCESSIBLE.
- STEER FOR ALTERNATE COURSE

RESULT OF PILOT'S PRESENCE:

- GLIDER SAVED
- MORE DATA RECOVERED

DS-022-129

This is another example in the use of the pilot where an unexpected situation is encountered.

Dyna-
Soar

EXAMPLE OF SPECIFIC PILOT ACTION

EVENT:

- UNEXPECTED STABILITY PROBLEM THREATENS IMMINENT LOSS OF VEHICLE IN TEST FLIGHT

AUTO. SYSTEM ACTION:

- CONTINUE PROGRAMMED TEST TO VEHICLE BREAKUP

PILOT ACTION:

- CHANGE ATTITUDE TO AVOID UNSTABLE REGIME
- PROBE REGION OF INSTABILITY TO DETERMINE EXTENT
- CONTINUE PROGRAMMED FLIGHT WHEN DANGEROUS AREA IS PASSED.

RESULT:

- PROBLEM AREA DEFINED
- USEFUL DATA OBTAINED IN SPEED REGIMES BELOW DANGER AREA
- GLIDER RECOVERED

DS-022-187

Experience with stability systems to date indicates this type of problem is likely to be a persistent one.

*Early show pilot forward
Statement of human redundancy
Lorrie*

Dyna-
Soar

EXAMPLE OF SPECIFIC PILOT ACTION

EVENT:

- NONCATASTROPHIC FAILURE OF GUIDANCE SYSTEM DURING GLIDE

AUTO. SYSTEM ACTION:

- CONTINUE FLIGHT TO STRUCTURAL FAILURE OR GROUND CONTACT AT WRONG PLACE

PILOT ACTION:


- DETECT FAILURE BY COMPARISON WITH BACK-UP INSTRUMENTS, PERSONAL OBSERVATIONS,
- ALTER PROGRAM TO ENSURE VEHICLE SURVIVAL AND REACHING LANDING SITE
- ATTEMPT TO LAND WITH AID OF GROUND CONTROL

RESULT:

- MORE DATA OBTAINED
- GREATER CHANCE OF RECOVERING GLIDER

DS-022-150

This is another example of specific pilot action that is taken in the case of a system malfunction.



SPECIFIC ACTIONS PILOT CAN TAKE

PILOT CAN:

- DETECT FAILED SYSTEMS AND SELECT ALTERNATE
- ALTER TEST PLAN IF IT THREATENS SAFETY OF VEHICLE
- PERFORM ADDITIONAL TEST TO PROBE PROBLEM AREAS
- ACQUIRE SUBJECTIVE DATA

RESULT:

- INCREASED CHANCE OF MISSION SUCCESS
- INCREASED VALUE OF DATA OBTAINED

DS-022-184

In summary, Dyna-Soar simulator studies and analysis indicate that the pilot can be used very effectively.

In some cases his use so increases the predicted chance of mission success as to make it worthwhile to consider elimination of unmanned orbital launches.



POTENTIAL EFFECT OF PILOT AND REDUNDANCY

BOMARC (60 ATTEMPTS)

	NO PILOT SINGLE	PILOT ONLY	DUAL ONLY	PILOT AND DUAL SYSTEM
MISSION SUCCESSES	26	34	30	51
ALTERNATE MISSION	0	1	0	7
TOTAL	26	35	30	58
AIRPLANES LOST	34			2

MINUTEMAN (4 ATTEMPTS)

MISSION SUCCESSES	1	1	3	3
ALTERNATE MISSION	0	1	0	1
TOTAL	1	2	3	4
AIRPLANES LOST	3	2	1	0

DS-022-180 GRP 4

The assumption was made that space, weight, and system design was such as to permit installation of a cockpit and pertinent manned-type dual systems. It was also assumed that the resulting craft would fly at the original altitude/velocity combination.

The results have been summarized in terms of the effect of the trade-off of pilot, and single and dual systems on mission success.

The end effect of considering a pilot with a dual system versus a missile with only a single system may be seen by comparing the estimated airplanes lost.



TRENDS DEMONSTRATED MISSILE AND AIRCRAFT PROJECTS

SYSTEM	NO. FL'TS	% SUCCESS		SAVED BY PILOT		DS FLIGHTS REQ		COST FOR AUTOMAT.
		NO PILOT	WITH	MISSIONS	A/C	PILOT	NO PILOT	
X-15	40	55	83	% LOST 95	% 100	18.5	31	200
BOMARC	167	51	82	87	87	19.2	35	262
BOMARC	60	43	85	94	94	18.7	41	354
MINUTEMAN	4	25	75	100	100			
MERCURY	6	66		50		21.6	27	139
REGULUS	784	81		29	29	21	22	62
JET AIRC'FT	1000	66			99.5		27	139
ROCKET AIRC'FT		61			89		30	185

DS-022-188, 81

The results of the independent interpretation of their own actual flight data by government and industry agencies is summarized.

These independent studies, when applied to Dyna-Soar, agree fairly closely as to the number of piloted flights required to attain 18 recoveries. Increased flights would be required for attaining 18 flights unmanned.

The important point illustrated here by these unrelated projects is the trend illustrated by the data rather than the exact numerical values. Based on the assumption that Dyna-Soar experience will parallel that in the pertinent rocket-research, jet aircraft, or missile project, the number of Dyna-Soar flights required for unmanned attainment may be deduced.

X-15 Experience — If Dyna-Soar experience parallels the X-15 experience, the use of the pilot is to save the 12.5 flights that would be required if the Dyna-Soar were unmanned. (As before, the detailed data from which these inferences were drawn, is included in Appendices C, H, and I.)

Bomarc Experience — The detailed data on 167 flights from which the Bomarc trends were obtained are included as Appendix D. The material analyzed includes the entire flight experience from Sept. 1952 through June 30, 1961.

TRENDS DEMONSTRATED — Missile and Aircraft Projects (Cont.)

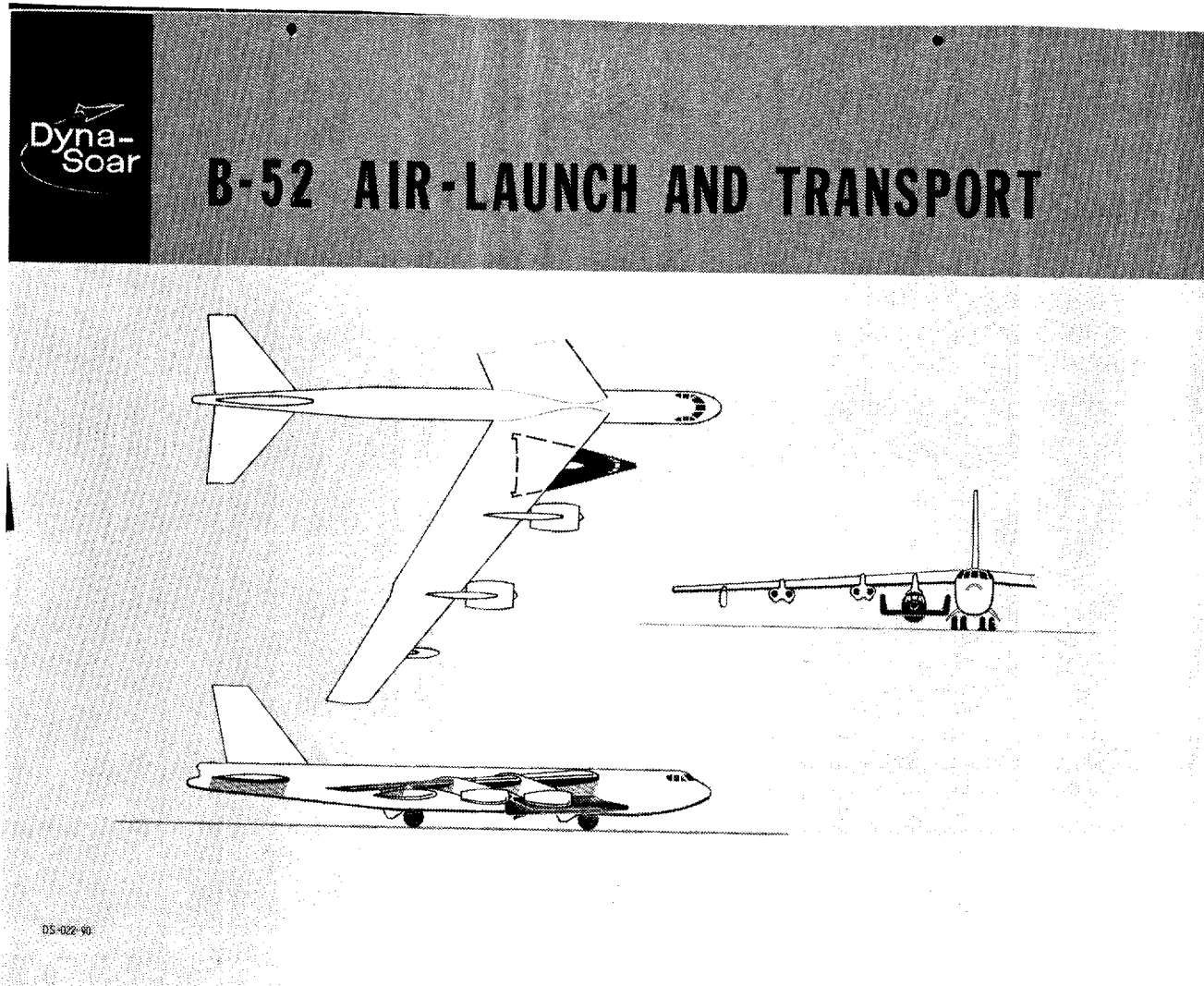
Mercury Experience — Data on the Mercury program was supplied by Mr. Showberry, Mercury Operations, NASA Space Task Group, Langley Air Force Base, Virginia, 11 July 1961.

Regulus-F8U Experience — Comparative data on 784 Regulus flights versus F8U experience was obtained from Chance Vought Aircraft Report E8R-11707 "Manned vs. Unmanned Vehicle, a comparison of" by D. G. Starkey, 19 September 1958. Supplemental data on the results from the first 100 Regulus flights was also obtained from D. G. Starkey and is included as Appendix E.

Jet Aircraft and Rocket Aircraft Experience — For assumptions and ground rules see material as extracted from NASA Flight Research Center Investigation of 1000 Jet Aircraft and 190 Rocket Aircraft Flights. NASA-FRC letter of August 9, 1960 to Commander ARDC, Attn: Mr. T. J. Keating, Subject: "Flight Research Center Manned Rocket Flight Study" from Paul F. Bikle, Director. This has been included as Appendix G.

Summary — Effect of Redundancy + Pilot-in-the-Loop — detailed data is included as Appendix I.

A noteworthy use of the Dyna-Soar pilot is the elimination of the hardware costs associated with unmanned operation. The cost estimate is defined in Appendix D. It covers only the costs of gliders and booster airframes consumed and excludes the cost of developing and qualifying the automatic system itself.



The Dyna-Soar system during the air-launch phase resembles previous research aircraft in that a "carrier" or "mother" aircraft is used to carry the glider aloft.

In another respect the Dyna-Soar is quite unlike previous research aircraft in that following the air-launch phase a man will be operating a glider in conjunction with a powerful booster.

MANNED BOOSTER CONSIDERATIONS

DS-002-188

The combination of a glider with a booster has a large effect on the considerations that must be weighed in arriving at an optimum amalgamation and trade-off of manned aircraft and missile characteristics.



INFLUENCE OF MAN ON BOOSTER DESIGN

- STRUCTURAL CRITERIA HAVE BEEN MODIFIED
- PAYLOAD RECOVERY CEILING MAY FORCE
HIGH BOOST DYNAMIC PRESSURE
- USEFUL PAYLOAD DECREASED BY ESCAPE ROCKET WEIGHT
- MALFUNCTION DETECTION SYSTEMS REQUIRED
- PILOT WILL REPLACE SOME AUTOMATIC FUNCTIONS
- PILOT WILL ADD TO MALFUNCTION DETECTION CAPABILITY
- SEARCH AND RESCUE MAY DICTATE LOCATION
AND AZIMUTH OF LAUNCH

US-002-290 CRP 4

These are some of the items that were influenced by manned considerations.



ON BOARD COUNTDOWN ROLE

- T-95 TEST INSTRUMENTATION SUBSYSTEM
- T-93 REACTION CONTROL SYSTEM, DYNAMIC
- T-85 ACCESSORY POWER UNITS
GLIDER ELECTRICAL POWER SYSTEM
GLIDER HYDRAULIC POWER SYSTEM
ENVIRONMENTAL CONTROL SYSTEM
- T-75 GLIDER AERO SURFACE CONTROL SYSTEM,
DYNAMIC
- T-60 AERO SURFACES TRIMMING

OS-022-204

One of the contributions from the use of man in Dyna-Soar becomes noticeable during countdown.

The pilot is assumed to enter the cockpit of the glider at T-97 (i.e., 97 minutes prior to launch).



PILOT COUNTDOWN ROLE

- T-30 COCKPIT PRESSURE CHECK
COMMUNICATIONS & TRACKING SUBSYSTEM
- T-26 PILOT-BOOSTER FLIGHT CONTROL SYSTEM
- T-18 REACTION CONTROL SYSTEM CONFIDENCE
- T-14 PILOT AERO SURFACE CONTROL SYSTEM
- T-12 ARM ABORT & SEPARATION SYSTEM
COMMUNICATIONS & TRACKING SUBSYSTEM
OPEN LOOP
- T-10 RECORDERS & CAMERAS

DS-02-001

By T-30 the count has progressed to the point of the cockpit pressure check.

The flight control systems of the booster and the glider reaction and aerodynamic controls are checked as in the practice with conventional aircraft.



PILOT COUNTDOWN ROLE (CONT.)

T-4	VERIFY:	
	SECONDARY POWER	COMM. & TRACKING
	SERVICING	FLIGHT CONTROLS
	MECHANICAL	PRIMARY GUIDANCE
	ORDNANCE	COCKPIT
	TEST INSTRUMENTATION	PILOT

T-3(SEC) VERIFY UMBILICAL HATCH
"HOLD-GO" SWITCH TO "GO"

DS-028-202

Final verification takes place at T-4.

A last-minute visual scan of the instrument panel is accomplished.

After T-3 seconds, launching is accomplished from the blockhouse.

Dyna-
Soar

PILOT'S ROLE

T-45 THRU T-0

PROBLEM: WHAT WILL THE PILOT CONTRIBUTE
FROM T-45 THRU T-0 ?

GIVEN: 1.D2-6909-2 SYSTEM DESCRIPTION
2.D2-80045 GCOE PERFORMANCE
REQUIREMENTS

RESULT: THE PILOT WILL PERFORM
END-TO-END FLIGHT READINESS
TESTS & TESTS ON PILOT
CONTROLS FASTER, EASIER, &
SIMPLER THAN CAN AUTOMATIC
EQUIPMENT

DS-022-373

These features of the pilot's role in the T-45 to T-0 area have emerged from the examination of the countdown.

His role was assessed against the system as it existed.

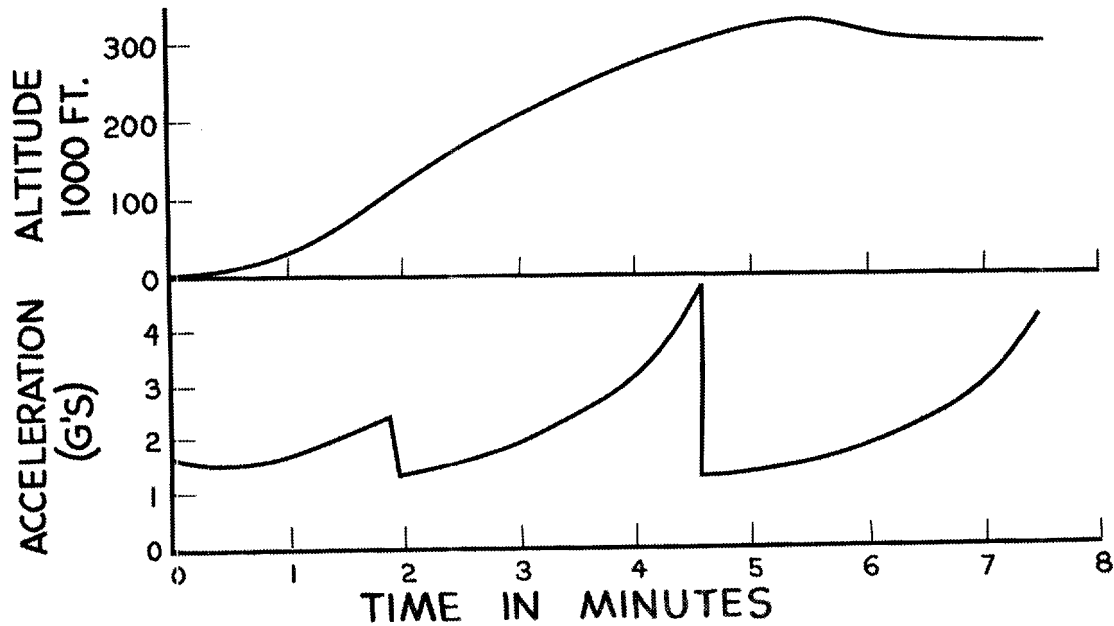
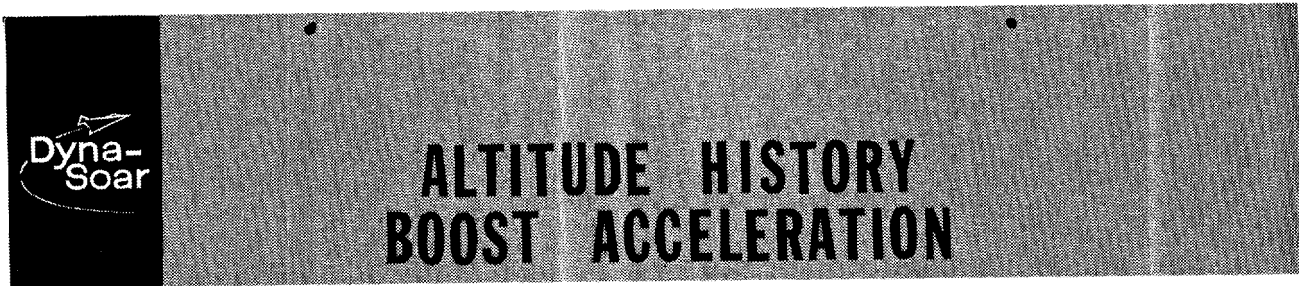
Dyna-
Soar

ADVANTAGES

- GCOE WILL BE DISCONNECTED AT T-40 RESULTING IN
 1. REDUCED RFI PROBLEMS
 2. ELIMINATION OF GCOE INDUCED ABORTS
 3. REDUCE UMBILICLE SIZE
- GCOE & LC & M EQUIPMENT WILL BE SIMPLER DUE TO PILOTS ABILITY TO
 1. OBSERVE
 2. EVALUATE
 3. DECIDE
 4. CONTROL

These advantages appeared to accrue from the use of the pilot during countdown.

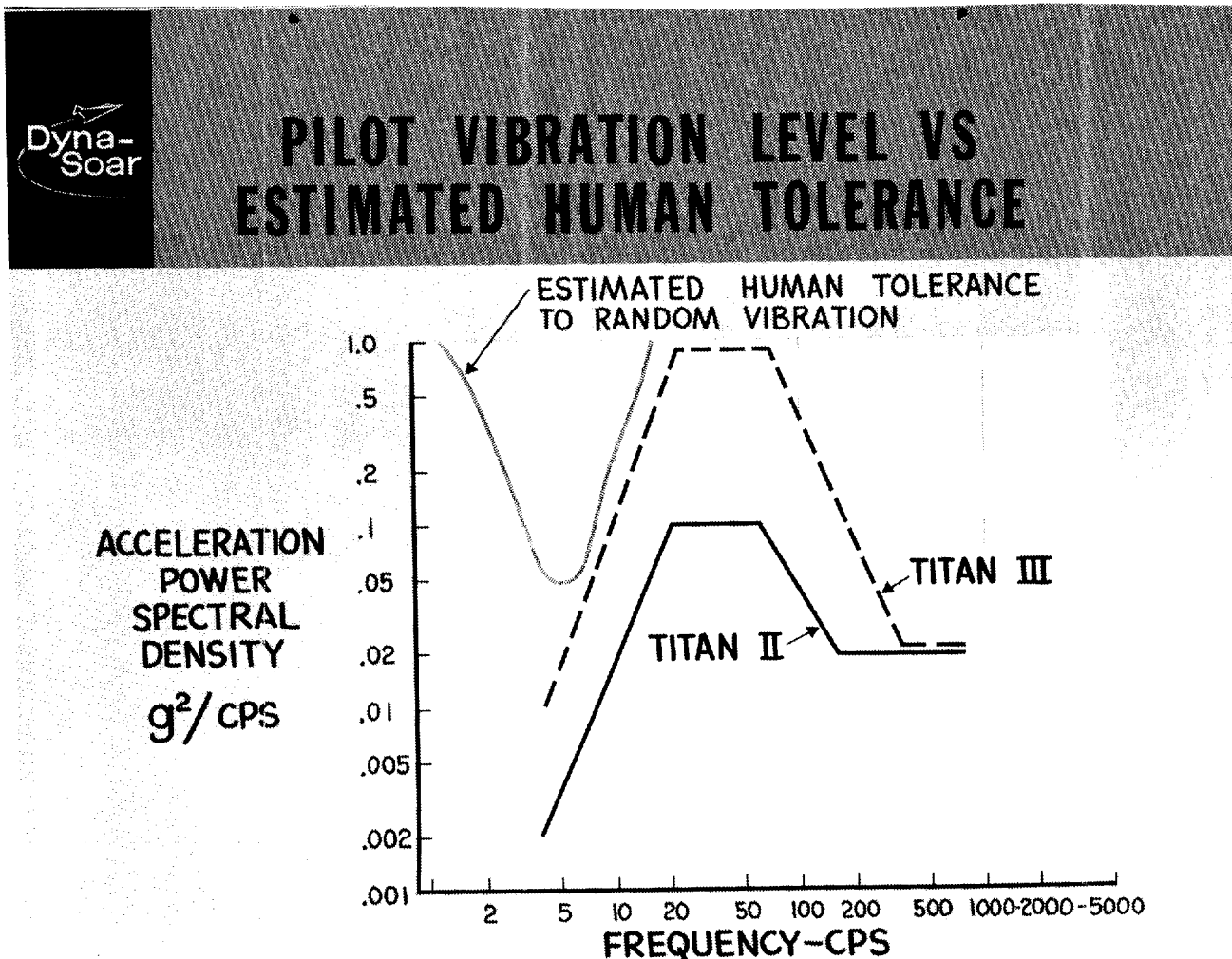
They permitted a reduction in glider weight and reduced what would have been the costs associated with full automatic checkout equipment.



DS-022-15

At the completion of the countdown, and after launch, the pilot operates in a transverse "g" or acceleration environment.

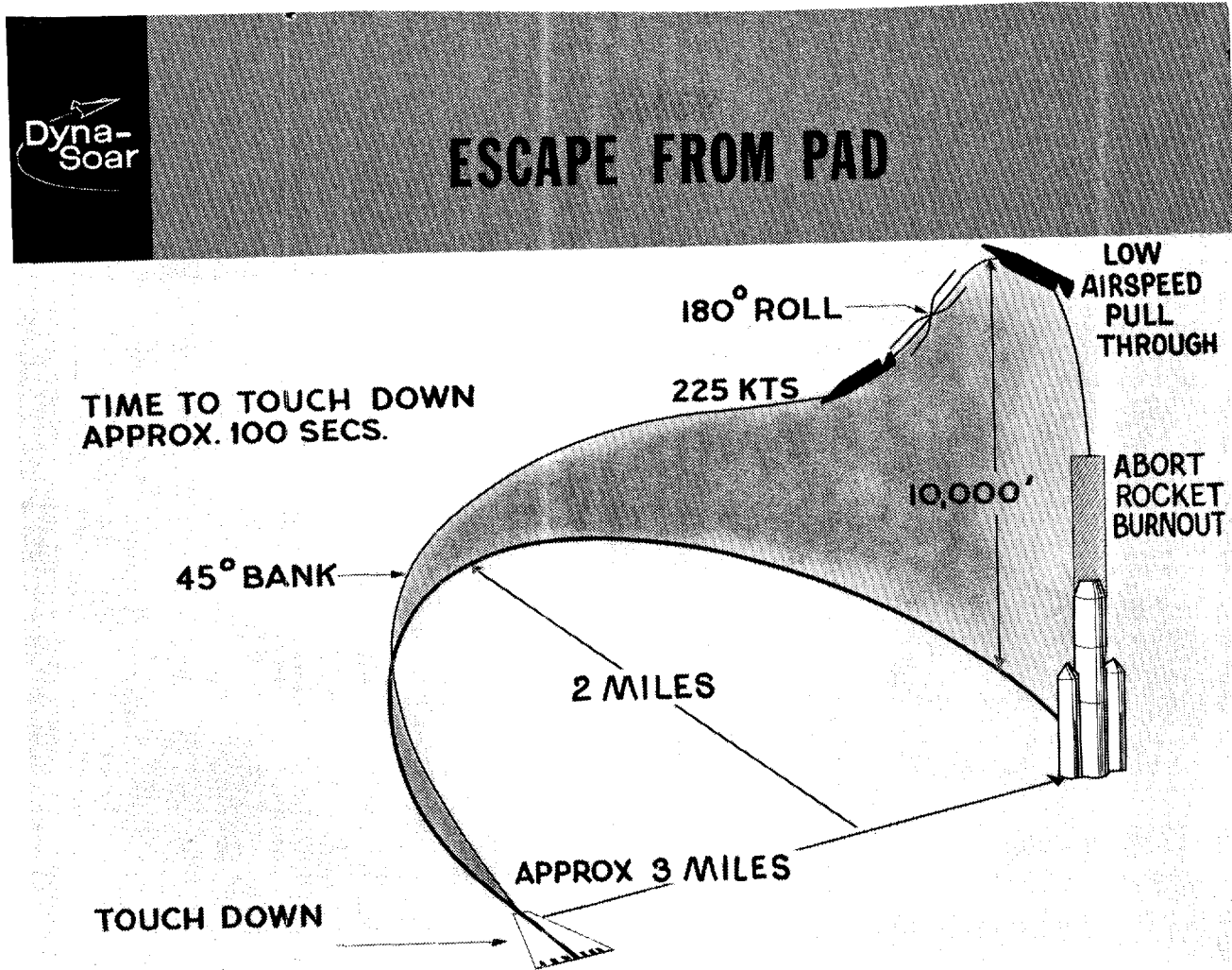
It may be seen that the total acceleration launch stress is less than that already encountered in the actual Mercury launches and the simulated launch aborts.



DS-012-59 R1

Coincident with acceleration, the pilot is exposed to a vibration field.

This vibration is induced by the anticipated exhaust characteristics of the Titan III. Although higher than that of the Titan II, the Titan III vibration characteristics are estimated to be within human tolerance. At one point the anticipated vibration is closer to the human tolerance than we would like and action is being taken to institute a greater margin.



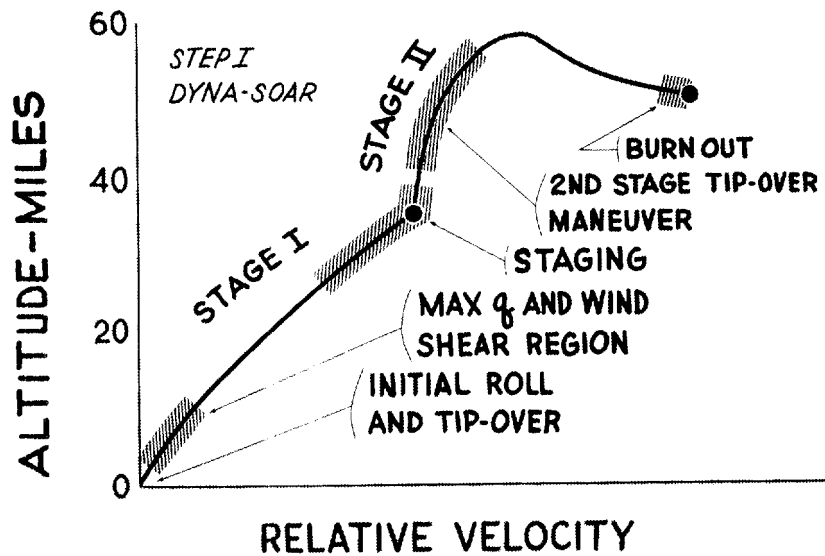
An abort system is included to facilitate escape during the launch operation and orbit injection.

These abort conditions have been flown by use of an F5D at the NASA-FRC Edwards, which was modified to the windshield visibility condition expected for Dyna-Soar. The W/S and L/D characteristics of the F5D resemble those of the Dyna-Soar closely enough to assess the abort landing situation.

No difficulty was encountered in making these landings.



BOOST CONTROL REGIONS



Simulator assessment has been made of the ability of the pilot to control the Step I air vehicle during boost.

The more difficult or critical areas are shaded on the chart.

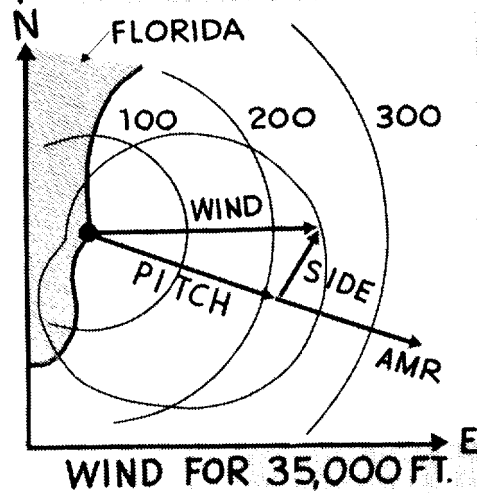
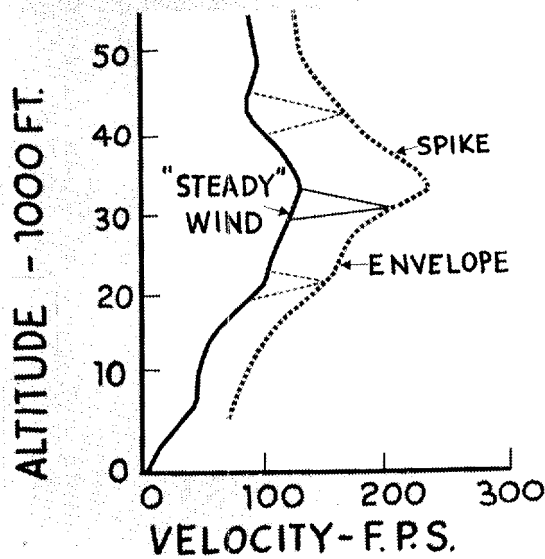


BOOST PILOT CONTROL~WIND PROFILE

3-AXES PILOTING TASK • PITCH-OVER PROGRAM & PITCH WIND

AVIDYNE WIND
(1% LOADS EXCEEDANCE)

- SIDE WIND
- ROLL-YAW COUPLING
(FIN & DIHEDRAL EFFECT)

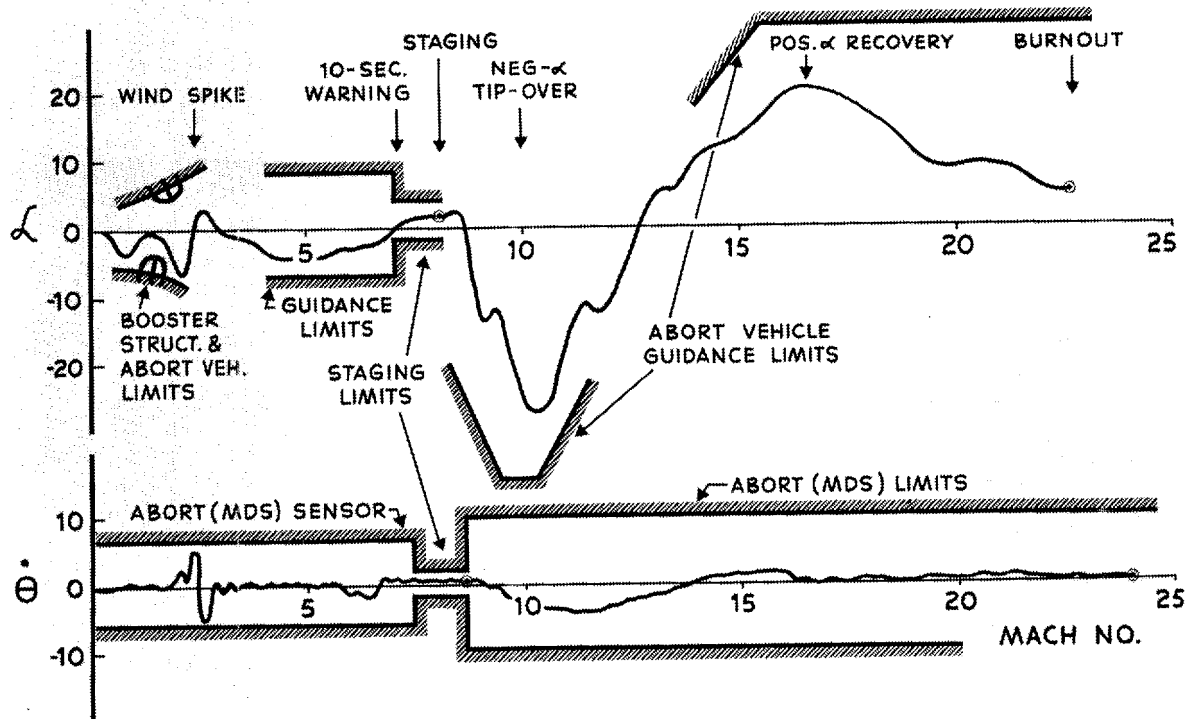


In addition to the tip-over or pitch-control task, the pilot was confronted with a wind problem.

The most severe wind case was assumed to be encountered in every boost mission.

Dyna-Soar

PILOT CONTROL DURING BOOST TYPICAL SIMULATOR TRACE

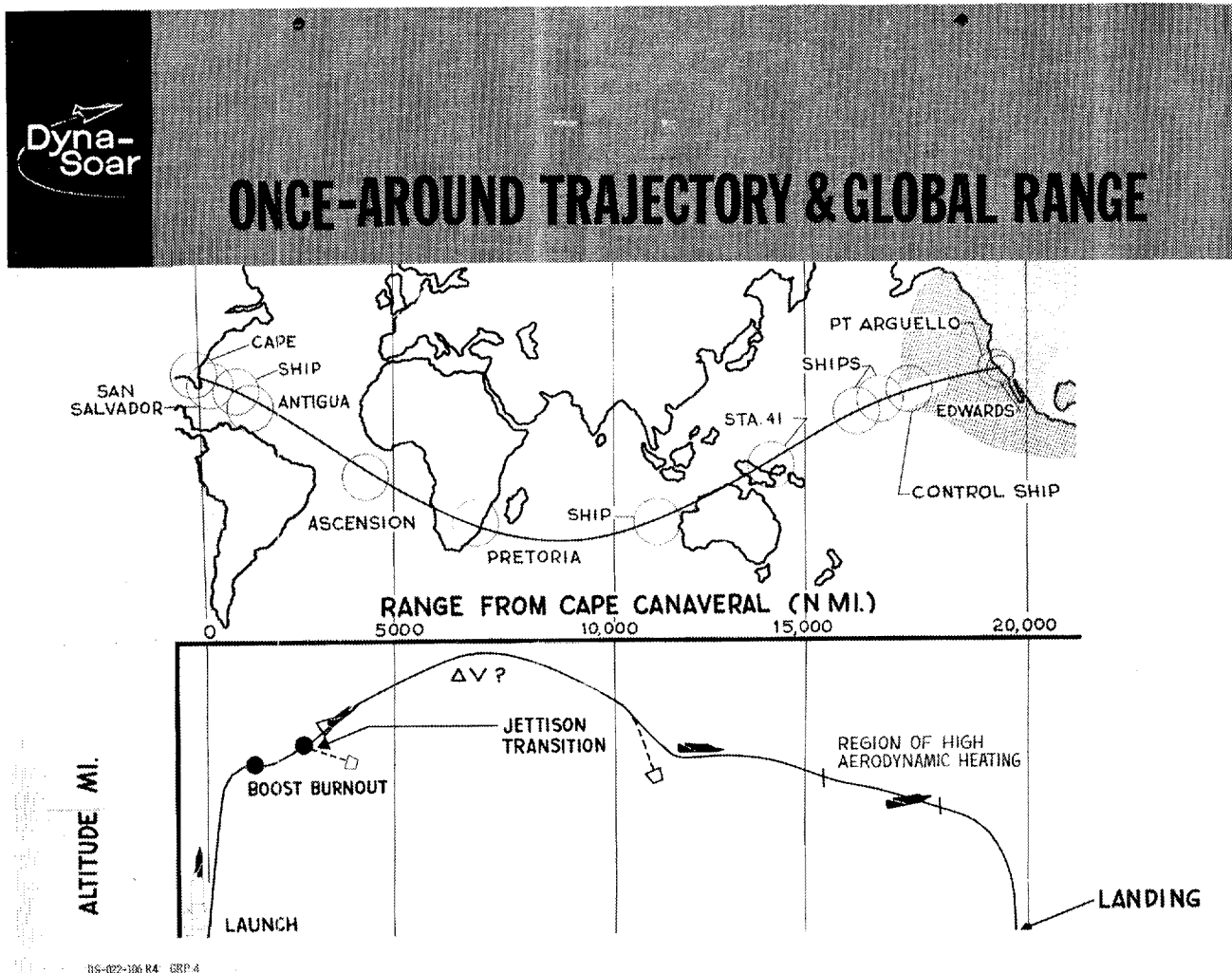


DS-002-208

The effectiveness of the pilot to exercise control during these conditions may be judged from examination of a typical simulator trace.

It was judged that the boost control task was no great problem during the fixed-base simulation program. A better verification for this preliminary conclusion can be gained from the results of the dynamic simulation on the NADC Johnsville centrifuge scheduled for the 28 May-16 June 1962 period.

It should be noted that these conclusions will be only as valid as the closeness with which the actual booster used in flight duplicates the characteristics assumed for the simulator.



At the conclusion of the boost phase the pilot is used continuously during the orbital phase.

A typical Cape Canaveral to Edwards Air Force Base ground path and altitude plot is depicted. Variations, particularly in altitude or in angle of attack, are being intensively studied to select the combination that will give the best combination of data acquisition and safety.



PILOT ROLE IN THE TEST PROGRAM

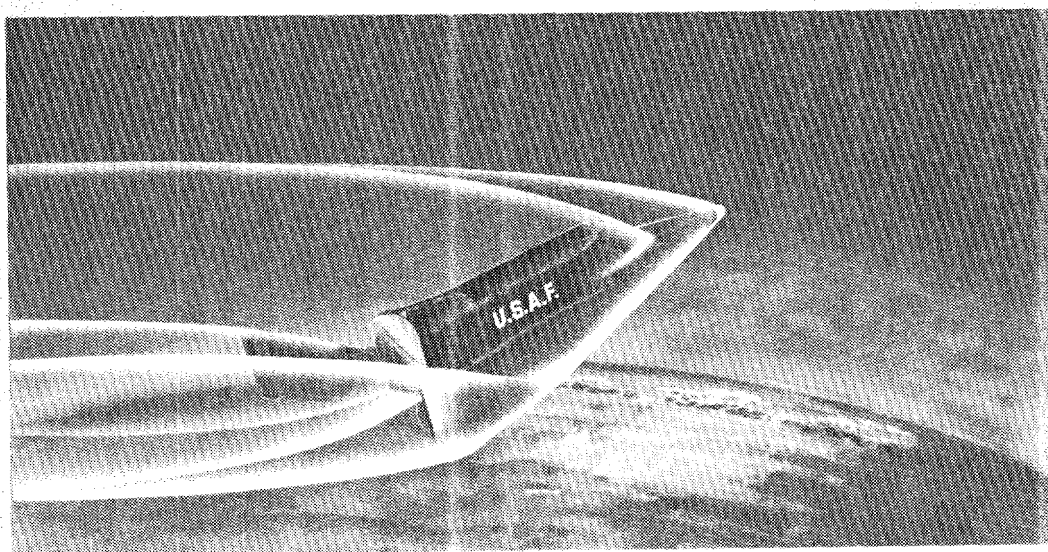
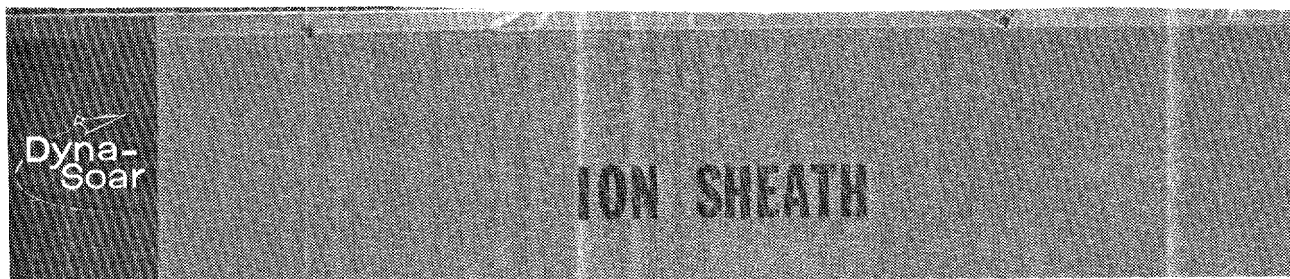
	FLIGHT TIME
IMPROVED QUALITY & QUANTITY OF DATA	
CONDUCTS TEST MANEUVERS	
EVALUATES SYSTEM RESPONSE DURING FLIGHT	
MODIFIES ENSUING MANEUVERS ACCORDINGLY	
OPERATES AUXILIARY TEST EQUIPMENT	
PROVIDES DATA REPORTING	
INCREASED MISSION RELIABILITY	
PROVIDES MISSION ALTERATION CAPABILITY	
PROVIDES RELIABLE MEANS OF GLIDER RECOVERY	(1) — — —
PROVIDES PRIMARY CONTROL	(1) — — —
PROVIDES PRIMARY NAVIGATION (TERMINAL LANDING SITE)	
ALLOWS BACK-UP NAVIGATION (ORBIT & RE-ENTRY)	
PROVIDES MALFUNCTION CORRECTION CAPABILITY	
PERMITS GROUND-TO-AIR DATA LINK	(2) — — —
ASSUMES RANGE SAFETY RESPONSIBILITY (AFTER BOOST)	
(1) RECOVERY FROM FAILURE DURING BOOST	
(2) LOCAL MALFUNCTION CORRECTION ONLY	

DS-822-195

A time line analysis was made of the use of the pilot loading during the total mission.

It may be seen that the pilot is used to give flexibility, reliability, and the advantages of on-the-spot decision making.

His use as a backup to the automatic or normal systems can be noted.

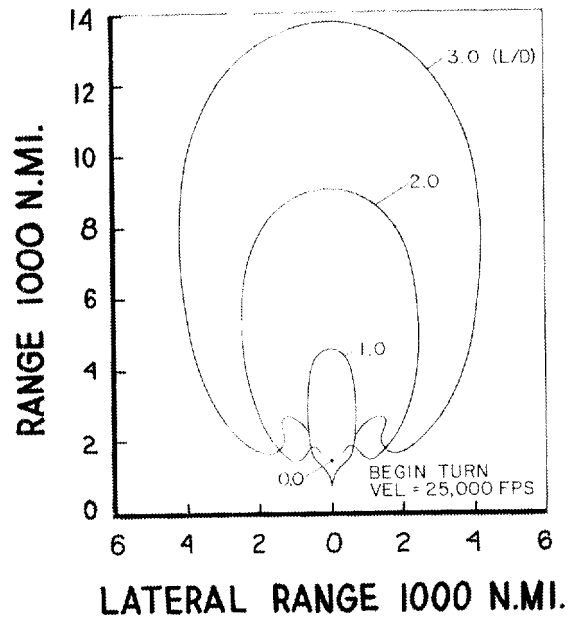
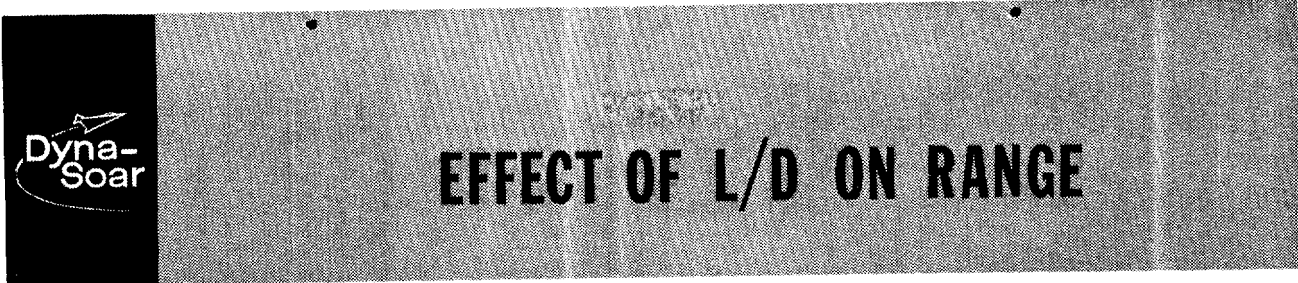


DS-522-46

One of the elements that must be more intensively evaluated for its effect on future research or military systems is the ion sheath as existing at projected Dyna-Soar flight levels.

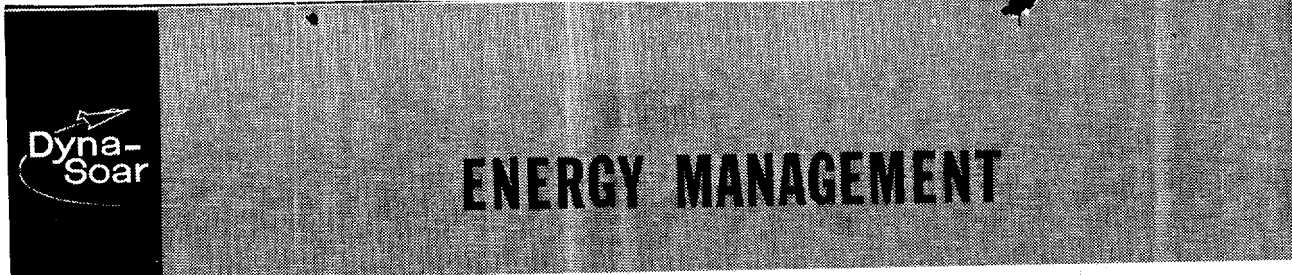
The ability of the pilot to see through the ion sheath is of great significance to use of backup attitude control or navigation systems that use the horizon or the ground as a point of reference.

The effect of the ion sheath on communications places demands on data transmission in particular.

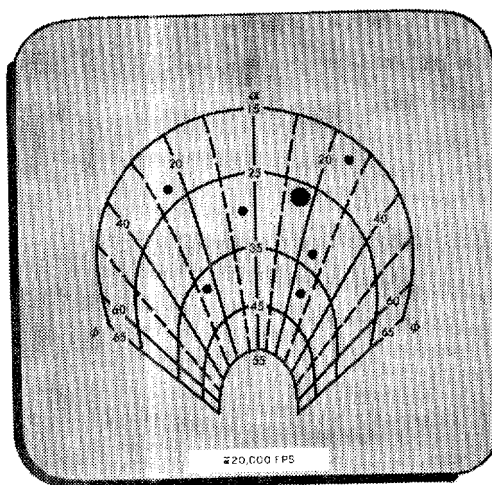


DS-022-98 GRP 4

One of the salient features of the design is the rather extensive longitudinal and lateral range afforded by the maneuverability of the glider.



RE-ENTRY & LANDING



DS-022-197

To use the pilot to best advantage in his flexible and decision-making capability, the attainability of selected landing sites is computed on-board and displayed to the pilot.



After the atmospheric re-entry is completed and the glider has reached the area of the landing field, man is used to accomplish a manual landing.

In this final phase, man is used to effect the landing from his vantage point in the cockpit. Reliability and cost studies indicate his use yields a distinct advantage when compared to an automatic landing system.

After landing, the debriefing of the man is used to give immediate qualitative data on occurrences during flight that may not have been instrumented for. These comments, along with the recorded data, will be used to correct the design of this and future space vehicles or to alter subsequent flight plans as appropriate.

Appendix A
Backup to DS-022-101

R & D PROGRAM OBJECTIVES

Statement of Work 620A-62-2

Early attainment of piloted orbital flight

Provide piloted, maneuverable gliders and associated support equipment for the conduct of flight testing in the hypersonic and orbital flight regimes to include:

Gathering of research data to solve design problems of controlled, lifting re-entry from orbital flight

Demonstrate piloted, maneuvering re-entry and effect a conventional landing at a preselected landing site

The testing of vehicle equipments and exploration of man's functions in space

Following successful orbital demonstration, to provide the capability for quick exploitation of technological advances through future tests

Dyna-Soar Approach

The program objectives will be attained by adapting the Dyna-Soar piloted winged body re-entry glider, initially designed under the Dyna-Soar Step I Program, for launch into orbit by the Titan III-C Booster. Maximum exploitation will be made of resources, experience, and knowledge now available.

Initial flight test of the piloted glider, air launched from a B-52, will be made at Edwards Air Force Base to demonstrate low supersonic, transonic, and subsonic flight and landing capabilities, operation of subsystems, and to conduct pilot indoctrination. Subsequently, ground launch flights with the Titan III-C Booster will be conducted at AFMTC. Orbital flights are planned for landing at Edwards Air Force Base.

The principal features of this program are: (1) a piloted spacecraft with lifting re-entry to provide maneuverability, low decelerations, a relatively wide flight corridor during re-entry, and the capability of landing with a conventional tangential landing at a preselected site; (2) man integrated into the system to exploit man's capability.

System Design Objectives

Specific system design objectives are specified in the Dyna-Soar System Specification, Document ASNR-62-4, and include:

Demonstration of successful boost from Cape Canaveral, orbital flight, re-entry and landing at Edwards AFB, with basic glider reusable for additional flights.

Acquisition during boost, orbital flight, re-entry and landing at Edwards of system development and research data measurements per flight from telemetry and on-board recording.

System design for inherent pilot safety

Reliability goal of the Dyna-Soar air vehicle (glider/transition/booster) of 95% for prelaunched checkout and countdown and 85% for flight.

Design with no significant differences in airborne systems between the unmanned and piloted vehicles for those items critical to reliability and pilot safety.

Minimum change to the Dyna-Soar glider designed during the Step I program to adapt it to the Titan III-C Booster for orbital flights.

Retention in the orbital glider of the payload capability inherent in the Step I design.

Test System Objectives

Development testing

- Energy management systems

Exploration

- Maximum heating regions

- Safe limits of glider performance

 - Structural heating and loads

 - Stability and control

 - Energy management during re-entry

Evaluation

- System Performance

- Environmental characteristics

- Degree of maneuverability and range variation

- Performance limits and tolerances for controlled landings.

Acquisition

- Data measurement

Demonstration

- Piloted glider maneuverability during orbit and re-entry

- Capability of man

 - Orbital and hypersonic flight regime

 - Control of a maneuverable orbital vehicle

 - Control during boost

 - Long range flight management functions

 - Effect conventional landing

 - Potential applications usefulness

Provide increased capability

- Piloted in-flight control and management

- Make decisions and take action in unusual situations

System Design Requirements

Communications and tracking

- Air to ground, ground to air, air to air
- Voice
- Command
- Beacon (rescue)
- Real time data
- Tracking acquisition
- Tracking beacon

Guidance

- Auto trajectory — lift off to beginning of landing
- Abort trajectory steering commands
- Inertial displays
 - Pilot manual control — normal trajectories to initial approach
- Backup information
 - Re-entry with failed primary guidance system
- Malfunction detection
- Attitude information
 - Control during landing

Environmental

Safety

Test Instrumentation System

Human Engineering

Reliability

Test System Requirements

System requirements to be met

- Orbital velocities
- Air vehicle configuration
 - Piloted medium L/D glider
- Transition section
- Global missions
- Test data and operational experience
 - Orbital and re-entry flight regimes
- Evaluation of performance versus objectives
- Air launch flights
- Air launch and ground launch
 - Training
 - Simulation
 - Data reduction
 - Maintenance

Appendix B
Backup to DS-022-186

SOME RELATIVE MERITS OF MANNED VS. UNMANNED DYNA-SOAR
WEAPON SYSTEM

I. DECISION MAKING CAPABILITY

A. Manned System

A rapid and accurate decision-making capability is provided by "on the spot" assessment of the situation by a trained observer. This capability is a continuous function as the on-board observer is in constant and direct contact with events requiring man-made decisions.

B. Unmanned System

Assessment of the situation by trained observers on the ground must necessarily await the receipt of relevant data that is available only when the glider is within range of a data acquisition station. This data, unlike that which can be made directly available to the on-board observer, is subject to inaccuracies imposed by data conditioning, transmission, reception and relay, processing and recording.

II. COMMAND CONTROL CAPABILITY (Quick Reaction Capability)

A. Manned System

An immediate and positive command control capability is provided. An on-board observer can initiate command control inputs to vehicle subsystems or payload subsystems in immediate reaction to observed conditions.

B. Unmanned System

Unprogrammed command control can be exercised only when the vehicle is within range of ground stations having a command control transmission capability. Additional equipment is required in the vehicle to provide verification to the ground that the command control transmission has been received and acted upon.

III. DETERMINATION OF VEHICLE AND PAYLOAD STATUS

A. Manned System

An onboard observer can rapidly and continually assess the gross operational status of vehicle and payload subsystems to determine capability to perform all or part of the mission.

B. Unmanned System

Determination of vehicle and payload operational status on the ground requires the transmission of relevant data to the ground and the processing of this data by complex ground equipment.

IV. POST-LAUNCH CHANGES IN MISSION PLAN

A. Manned System

Post-launch changes in mission plan can be fed into the vehicle and payload subsystems via ground to air voice instructions to the on-board observer.

B. Unmanned System

The mission program or plan depends on predetermined programs inserted into the subsystems prior to launch.

V. PAYLOAD REDUNDANCY

A. Manned System

An on-board observer can augment certain payload functions or assume some payload functions in the event of payload subsystem breakdowns.

B. Unmanned System

In the event of payload subsystem failure, unless redundant subsystems are used, the entire mission can be a wasted effort.

VI. MISSION DATA REDUNDANCY

A. Manned System

Mission data available from subsystems can be verified by information from the on-board observer through the media of air to ground voice and postflight debriefing.

B. Unmanned System

Ground analysis is dependent upon only automatically acquired data.

VII. MISSION DATA AUGMENTATION

A. Manned System

An on-board observer possesses the capability to acquire data of broad scope, either by intuition and judgment or by in-flight interrogation and instructions from ground personnel.

B. Unmanned System

Data acquisition is limited by the capability designed into the subsystems (black boxes).

VIII. RECOVERY OF ON-BOARD PAYLOAD DATA

A. Manned System

Piloted re-entry increases the probability of recovering the original on-board payload data. Pilot has capability for maneuvering the glider to meet unforeseen or abnormal situations and can choose primary or alternate landing sites. In the event of a catastrophic situation, the pilot can relay observed mission data to the ground by voice.

B. Unmanned System

Glider control is limited to prelaunch inserted programs and range limitations of ground control equipment. On-board original data records are more subject to loss or damage.

IX. ACCOMPLISHMENT OF MISSION DETAILS

A. Manned System

An on-board observer can optimize the gathering of mission data by providing direct adjustment or control of payload subsystems. Based on gross mission requirements, the observer serves as a vernier controller.

B. Unmanned System

Adjustment or control of subsystems from the ground is a remote step function process, limited by equipment design capabilities.

X. SUBSYSTEM COMPLEXITY

A. Manned System

An on-board observer is considered to be a general-purpose subsystem with a general-purpose compute capability to store data and analyze events. Less complexity in airborne and ground supporting subsystem equipment is required if the airborne observer assumes some of the subsystem functions.

B. Unmanned System

Subsystems designed to perform all functions required are necessarily complex with attendant reliability problems.

XI. EARLY MISSION TERMINATION AND RECOVERY

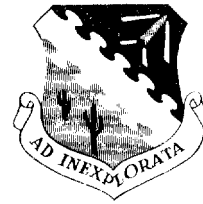
A. Manned System

On pilot decision, return from orbit can be made from any point because of the availability of pilot decision and inherent vehicle maneuverability.

B. Unmanned System

An unmanned system is committed to mission termination based on on-board programming and the availability of geographically opportune ground command sites.

HEADQUARTERS
AIR FORCE FLIGHT TEST CENTER
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS AIR FORCE BASE, CALIFORNIA



REPLY TO
ATTN OF:

FTFES

SUBJECT: Redundant Systems and Pilot-in-the-Loop Aspects of All X-15 Flights

TO: AFPR, TBC, Seattle, Washington
The Boeing Company
ATTN: Mr. T. K. Jones
Seattle, Washington

1. In accordance with agreements reached on 16 and 17 September 1961 among Mr. T. K. Jones of The Boeing Company, Mr. Hodapp of the Dyna-Soar SPO, Mr. J. L. Wesesky and Mr. R. G. Nagel of the AFFTC, the attached information will provide the necessary information on redundant (or back-up) systems and pilot-in-the-loop aspects for all forty X-15 free flights conducted to date. It is understood that this information will be combined by The Boeing Company with similar studies conducted on other manned and unmanned aerospace systems. It is further understood that this assimilated information will subsequently be provided to the Dyna-Soar SPO to assist that organization in justifying the benefits of redundant or back-up systems and the necessity for pilot-in-the-loop for Dyna-Soar.
2. In addition to the forty X-15 free flights covered in the attached material there have been thirty-one "no-launch" X-15 flights conducted to date; that is, on each of these thirty-one flights difficulties arose after B-52/X-15 mated take-off which forced flight cancellation prior to X-15 launch from the B-52 carrier aircraft. Effort in the current study by the AFFTC has been concentrated on the X-15 free flights, so the short time available has not permitted similar documentation of the "no-launch" flights. However, the study can be extended to the X-15 "no-launch" flights in the near future if there is a requirement for this information. The attached "X-15 Flight Record" (Attachment 1) lists all seventy-one X-15 flights to date in chronological order to show the distribution of "free" and "no-launch" flights.
3. Development of the X-15 hardware requires some explanation for clarification of the malfunctions shown in this study. The initial landing gear was proven inadequate and required modification to sustain landing loads of piloted flight. Design requirements of the landing gear for an automatic landing system are not known and their effect neglected in this study. The ballistic control system (reaction control) has not been developed to date, though it has not hindered the program since there have been no requirements on the flights performed thus far. The inertial guidance system, providing attitude, velocity, and altitude information to the pilot, has not performed satisfactorily.

The early flights with the XLR-11 engines required attitude information only while relying on the air data system and ground call-out for accurate velocity and altitude. Hence the inertial system (stable platform) was not noted as a malfunction except where the attitude system failed as well. Later flight required removal of the nose boom, destroying the value of the air data system. Reliance on the inertial system was required for these flights and hence malfunctions of the inertial computation are noted in the study.

4. For purposes of comparison in this study it has been assumed that unpiloted X-15 flights could be performed using existing X-15 subsystems by adding necessary autopilot and remote control functions. It is recognized that the subsystems for an unpiloted vehicle would be designed according to different criteria than those designed for piloted flight; thus a true comparison from the designer's viewpoint is difficult to make. Overall program results, however, in terms of flights per calendar time and data return per flight are considered valid comparisons.

2 ATTCH

1. X-15 Flight Record (4 copies)
2. Detailed History — Redundant
Sys & Pilot-in-the-Loop
Aspects for All X-15 Free
Flights, dtd 20 Sep 61 (4 copies)

Appendix D

Backup for DS-022-198 - 167 Bomarc Flights

Analysis of Individual Bomarc Flights

Success Summary Relationships

Actual vs. Expected Success for "Pilot Controlled" Flights

Total BOMARC flights (Sept. 1952 — June 30, 1961)	<u>167</u>
Successes (85 to 100%)	<u>*85</u>
Partial Successes (25 to 85%)	<u>62</u>
Unsuccessful (Less than 25%)	<u>20</u>

Expected Flight Success for "Pilot Controlled" Flights

Successes	<u>137</u>
Partial Successes	<u>19</u>
Unsuccessful	<u>11</u>

Basic assumptions:

1. Pilot replaces flight control and hydraulics systems.
2. Pilot has voice communication channel as auxiliary.
3. Pilot can override target seeker.
4. Pilot can control ramjets.
5. Aircraft can make second attack.

Possible reasons for disagreement on flight improvement:

Assumption 3: It was assumed that all Century-series fighters include target seekers as integral and essential portions of the fire control equipment. The seeker must therefore be operational for a successful mission.

Assumption 4: Ramjet events occur with great rapidity, and automatic control is utilized. It may be doubtful for pilot control to do other than to degrade ramjet performance.

Assumption 5: Because of the high speed, the aircraft turning radius is very large, and considerable time would be required to make a second attack. The usefulness of assuming a second attack may be questioned.

* For this study, this number assumes flights of 624-21 and Y-18 were successful. Previously these two flights were downgraded to "Partial successes" because of loss of data prior to interception.

Expected Flight Improvement for "Pilot Controlled" Flights

Missile No.	System Responsible	Nature of Problem	Expected Improvement Change *
Block II June — Sept. 1953			
623-3	F/C	Hardover elevator	P to S
Block IIIA Aug. 1954 — July 1955			
623-7	F/C	Hardover elevator.	U to S
623-12	F/C	Misaligned yaw rate gyro- oscillations destroyed rudder.	P to S
Block IIIB Feb. — July 1956			
623-14	F/C	Oscillations in roll and yaw.	P to S
623-17	T/S	Internal lock-on precluded target acquisition.	P to S
Block IVB July 1957 — Jan. 1958			
624-7	B/N Dest.	Extraneous destruct signal triggered destruct.	P to S
624-10	R/J	Ramjet blowout — apparent early Mach cut-in.	P to S
624-12	C/S	No response to missile azimuth heading commands.	P to S
624-13	C/S	Delayed response to dive command.	P to S
624-14	WCE	Radar errors led to mis- positioning.	P to S
Block IVC Mar. — Aug. 1958			
624-17	R/J	One engine did not go to rich limit.	P to S
624-18	T/S	Did not lock-on to available target.	P to S
624-25	F/C	Yaw rate channel out.	U to S

* S = Success, P = Partial Success, U = Unsuccessful

16XY Aug. 1958 — April 1959

XY-3	C/C	Short circuit in C/C provided pitch-down command.	U to P
XY-16	C/S	Premature dive.	P to S
XY-12	C/C	Stable platform drifted, missile off course.	P to S

200AY-1 Jan. — April 1959

Y-21	T/S	Acquired cloud.	P to S
Y-29	WCE	Computer programming error — off course.	P to S
Y-28	T/S	Antenna rate loop malfunctioned.	P to S
Y-37	WCE and B/N	Lost track and overshoot target.	P to S
Y-30	C/S	Dive timer ran down early.	P to S

200AY-2 June — Oct. 1959

Y-24	C/S	Late dive.	P to S
Y-41	C/S	Azimuth control malfunctioned.	P to S
Y-44	C/S	Erroneous launch azimuth — destroyed.	U to S
Y-43	F/C	Loss of damping signals.	U to S

Contractor Review Feb. — Aug. 1960

-6248	F/C	Instability in roll or yaw.	P to S
-6260	T/S	Antenna lost track—slewed to stops.	P to S
-6258	C/S	Did not dive on command.	P to S
-6263	F/C	Erroneous azimuth heading.	U to S
-6944	Processing	Error in aligning C/C.	P to S

Category III Jan. 1961 — Present

-1938	F/C	Off course —destroyed.	U to S
-6964	WCE	Commands not acceptable.	P to S
-6947	WCE	Commands not acceptable.	P to S
-1951	C/S	Did not dive on command.	P to S

631- Block I May 1959—April 1960

631-2	R/J	Lean limit blowout.	P to S
631-3	R/J	Blowout, angle of attack.	P to S
631-4	R/J	Blowout, drop in fuel flow.	P to S
631-6	R/B	Roll bulkhead servovalve failed.	P to S
631-8	F/C	Mach servo failed.	U to S

D2-80726

631- Block II April 1960 — Present

631-12	C/S	Radio frequency interference.	P to S
631-13	C/S	Radio frequency interference.	P to S
631-15	F/C	Erroneous launch heading — destroyed.	U to S
631-20	WCE, C/S	Data link incompatibility.	P to S
631-18	T/S	Did not lock-on (small target)	P to S
631-17	T/S	Improper test point termination	P to S
631-24	T/S	Continuous false detections.	P to S
631-25	F/C	Surface effectiveness servo malfunctioned.	P to S
631-28	T/S	Loss of lock-on, reorientation of antenna.	P to S
631-30	T/S	Satisfactory flight — downgraded for objectives.	P to S
631-29	T/S	Loss of lock-on, reorientation of antenna.	P to S
631-32	WCE	Erroneous target height inputs.	P to S

IM-99B Cat. II Jan. 1961 — Present

B-2	T/S or F/C	Erroneous guidance.	P to S
B-11	T/S	Did not lock-on to accessible target.	P to S

Appendix E

Backup to DS-022-198 - Regulus I Flights

EFFECT OF REDUNDANCY + PILOT-IN-THE-LOOP

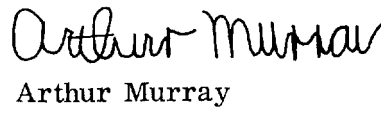
First 100 Regulus Flights

At the request of A. K. Murray of Boeing, D. R. Starkey of Chance Vought has completed an analysis of the first 100 Regulus flights based on archive data. In examining data from the archives, it was found that in these 100 flights there were 15 (unintentional) early expenditures or failures resulting in complete loss of the missile. The resulting success rate was found to be .85. This was achieved by having well-trained contractor personnel, advice of Engineering personnel well-versed in the design, manufacture, and qualification testing of the equipment, close control which could be extended by the contractor in-house, government furnishing of duplicate chase planes, etc.

It should be noted that in turning the missile over for Navy operation, the reliability for the year of 1954 dropped to .69. This average of .69 was made up from a .59 success rate for ship-based launches, and .79 for land-based launches. By training Navy personnel and Chance Vought technical advice, average success rate had increased to .77 by 1955 and .85 for 1956. The detailed data which follows on the 100 Regulus flights follows the same ground rules as were used for preparing the 784 flight analysis; that is, it was estimated the pilot would be aboard with suitable displays and airplane controls and there would be no redundant systems. Again it was noted that the success rate for operational use with trained personnel did not quite duplicate or come up to the success rate achieved by the contractor during the development program.

The summary of the first 100 flights shows that of the 15 losses, 9 could have been saved by having a pilot aboard and 2 additional could probably have been saved by pilot aboard. To eliminate controversy we're considering that 9 only rather than 11 could have been saved.

Contrasting Regulus (unmanned) flights with manned F8U flights, it was seen that during the first 100 flights of the F8U only one aircraft was lost and this was caused by structural failure which it is believed would have happened to the manned or unmanned vehicle.


Arthur Murray

Attachment A

A Murray/mj

Page One

Summary of the following data indicates that of 15 losses experienced during the first 100 Regulus flights, inclusion of a pilot would have saved 9 vehicles as indicated by the asterisk.

- * 1. After normal take-off, the stabilization system failed during climb. The missile entered a steepening turn and crashed nose down and inverted. Pilot could have saved the vehicle.

- 15. Missile was lost during let-down due to failure of the control system caused by circuit malfunction. Missile entered a dive and did not pull out. Normally a pilot would be expected to save the vehicle from this type of loss. However, it is not absolutely certain that the pilot's manual control inputs would have by-passed the malfunctioning component. Not considered as a "save" to eliminate controversy.

- 18. The hydraulic system malfunctioned during climb. It's possible that a pilot might have saved the vehicle if a hand pump had been available. Since the inclusion of a hand pump of this type is not necessarily standard procedure, there is some question as to whether a pilot could have saved the vehicle. Therefore, to eliminate controversy, this is presented as a loss that the pilot would not have prevented.

- * 22. Missile was lost during inbound turn because of weak control signal and radio command interference. The pilot probably could have eliminated the need to destruct the vehicle.

- * 30. Low-altitude assault pass under Navy flight control. Vehicle could have been saved by pilot operating a normal manual fuel selector.

- 36. The booster did not eject; therefore, the climb bias remained engaged. This vehicle could not have been saved by the pilot.

- 38. Booster rocket ejection fitting failed to operate; did not eject. Vehicle stalled on approach. Pilot may have been able to save the vehicle. Not counted as a possible "save" to eliminate controversy.

- * 39. No command control caused the loss of the vehicle. Lack of either chase airplane or ground system signals permitted the vehicle to crash. A pilot would have continued to fly.

- 46. Left booster fired 6 seconds after right. Thrust misalignment caused the vehicle to describe an erratic path terminated by the fuselage and elevator striking the lake bed. This could not have been saved by having a pilot aboard.

- * 52. Flight termination command inadvertently activated by ground crew. This destruct system would not have been in a manned vehicle.

Page Two

- * 63. Following launch, hard-over nose-down signal was generated due to loss of pitch reference. Missile struck the water nose low and was destroyed without burning. Pilot could have saved this one.
- * 68. The missile began to roll 7 minutes after take-off. Handing over control of the missile from one remote system to another was not effective. The missile was lost in the transfer. A pilot aboard would have taken over.
- * 77. Pitch oscillation developed in the Sperry climb control during the approach phase of flight. The landing sequence operated early. Gear came down too soon, and the combination caused the airplane to crash on approach. A pilot would have saved the vehicle by eliminating the pitch oscillation and delaying the extension of the gear to a more favorable time.
- 90. Left main gear failed to extend during approach; the missile cart-wheeled on touch-down. The pilot would not have saved this vehicle.
- * 91. The TROUNCE I decoder malfunctioned 1 hour and 20 minutes after launch. Need for a decoder would have been eliminated by pilot.

- * In analyzing the Regulus data from the first 100 flights, the Chance Vought ground rule of "pilot + single system - (no redundancy)" was followed with a projected success rate for manned flight of 94 percent.
- ** The pronounced improvement afforded by including the pilot and then giving the pilot more tools to work with, i.e., redundancy, is illustrated by the pilot + redundancy success rate of 98 percent.

Cost for Automation

Delta cost does not include range and communication network for automatic control system (SAGE or equivalent)

Unit Cost/flight = \$15.4 million (booster hardware consumed only)

Base flight quantity in all cases = 18

For example:

X-15 experience would indicate that 31 DS flights would be required to accomplish 18 missions.

X-15 experience	=	31
DS flights desired	=	18

Flights	=	13 x 15.4 = 200.2
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Appendix G

Backup to DS-022-198

**N A T I O N A L
A E R O N A U T I C S
A N D S P A C E
A D M I N I S T R A T I O N**



IN REPLY REFER TO

FLIGHT RESEARCH CENTER
BOX 273, EDWARDS, CALIFORNIA
CLIFFORD 8-2111 TWX: EDWARDS CAL 7347

August 9, 1960

From: NASA Flight Research Center

To: Commander
Air Research and Development Command
Wright Air Development Division
Directorate of Systems Management
Wright-Patterson Air Force Base
Dayton, Ohio

Attention: Mr. T. J. Keating, Ass't Chief,
Dyna-Soar Engineering Office

Subject: Flight Research Center Manned Rocket Flight Study

Ref: WADD letter to FRC, dated 6/14/60, jt/38109

1. In response to the request of the reference letter, the results of an investigation of the Flight Research Center's manned rocket flights and incidents encountered are enclosed along with the Flight Research Center's comments.

2. The Flight Research Center trusts the information and comments will be useful in evaluating the role of man as an integral part of an aircraft control system and in the preparation of your paper "What Price Man?"

Paul F. Bikle
Director

Enclosure
(1) Summary

JG/TFB:fhs

TAT

DEB

D2-80726

60

NASA-FRC

FLIGHT RESEARCH CENTER MANNED ROCKET FLIGHT STUDY
SUMMARY

A study of NACA-NASA manned rocket flights and the number and types of incidents encountered in connection with the flights was made at the request of Mr. T. J. Keating, Assistant Chief, Dyna-Soar Engineering Office, WADD. The purpose of the study was to provide some statistical-type data on manned rocket flight to aid in determining the value of using a human pilot as an integral part of a rocket-aircraft control system.

A total of 190 NACA-NASA manned rocket flights were studied. During these flights, 84 incidents were experienced. Thirty-four of the incidents, or approximately 18 percent of the flights investigated were serious enough that loss of the aircraft could have resulted. The data compiled, although not necessarily complete or 100-percent correct, are considered accurate enough to indicate the trends and the percentage of incidents encountered. A summary of these flights is shown in Table I. The individual flight tabulation from which Table I was derived will be forwarded on request.

From this investigation and from the Flight Research Center's manned rocket-flight experience, the FRC firmly believes that a human pilot should be considered a necessary complement to a flight control system to obtain the greatest reliability, versatility, and mission accomplishments. Two pilots at this research center are experienced rocket pilots, one with 46 rocket powered flights and the other with 30 rocket powered flights. Their thoughts on manned versus unmanned vehicles are especially appropriate, since they have been subjected to many of the inflight incidents previously described. Their comments and the pilot's role in flight research are attached. Your attention is also called to a paper presented at the ARS semiannual meeting of May 9-12, 1960, entitled, "The Pilot's Contribution to Mission Reliability on the X-15 Program," by James R. Drake, which discusses the pilot's contributions as a servomechanism and a programmer and considers his effect on vehicle reliability and weight.

From a similar investigation of 1,000 research and support-type NASA jet-aircraft flights (see Table II), 151, or approximately 15 percent, experienced serious incidents. A comparison of rocket flights with jet flights indicates that the percent of serious incidents occurring in rocket flight is not appreciably greater than that encountered in research and support jet flights. However, it should be pointed out that a comparison of this nature is somewhat compromised because of the increased emphasis on top-quality maintenance and proper operation of rocket vehicle systems as opposed to the routine maintenance performed on the jet aircraft.

DISCUSSION

The flight data and pilot's notes on rocket flights performed by agencies other than NASA were not complete enough to warrant an investigation of these flights; however, available Air Force and contractor flight records are noted in Table I, but were not used in compiling statistical data (except for the X-15). Flights that were scheduled as glide flights only, those which were aborted before drop, or those on which the rocket airplane was intentionally jettisoned due to an emergency from the carrier airplane were not included in compiling statistical data.

One such aircraft was lost by NASA when the rocket aircraft experienced an explosion prior to planned launch. The pilot was able, with the help of the crew of the carrier airplane, to climb into the bomb bay before jettison. On another attempted rocket flight, the pilot of the rocket airplane decided to abort the flight just prior to launch because of improper operation of the propellant-pressurization system. Simultaneously, the propeller governor system of the number 4 engine of the carrier airplane failed. The pilot of the carrier airplane jettisoned the rocket airplane with the pilot aboard. The rocket pilot successfully jettisoned all rocket propellant and landed the airplane without further incident. The number 4 propeller subsequently broke away and passed through the carrier airplane in the bomb-bay area where the rocket airplane is normally suspended. The carrier airplane was landed successfully, although it was badly damaged.

As mentioned previously, of the 190 NACA-NASA rocket flights investigated, there were 84 flights in which an incident was experienced. These incidents are further classified into serious (*) or minor (-) incidents as follows:

Serious incident (*) is any incident which, assuming an automatically controlled vehicle, could cause loss of the aircraft:

Examples:

1. Loss of aircraft stability due to design inadequacy
 - (a) $C_{N_{\beta}} = 0$
 - (b) Etc.
2. Loss of propulsion
3. Systems failure
 - (a) Control
 - (b) Guidance
 - (c) Etc.
4. Complete radio and/or telemetry failure.

Minor incident (-) is any incident which affects the flight but does not necessarily place the vehicle in jeopardy.

Examples:

1. Incorrect fuel-gage indication
2. Circuit breaker popping in flight
3. Intermittent radio operation
4. System malfunction
 - (a) Afterburner
 - (b) Landing gear
 - (c) Pressurization
 - (d) Etc.
5. Drag-chute malfunction
6. Flight instrument inoperative or incorrect
7. Improper engine operation

Note: On several flights, one or more rocket chambers failed to fire.

In conjunction with the rocket flights, 1,000 research and support jet-aircraft flights were investigated. The individual data for each flight recorded is available and may be obtained if desired. A summary of these flights is presented in Table II.

The following facts, opinions, and comments were developed from the investigation of the 190 rocket and 1,000 jet-aircraft NASA flights.

The Flight Research Center firmly believes that a human pilot should be considered an integral component of a flight control system. The human operator provides a capability for immediate evaluation and modification of the flight plan or for a successful abort during any phase of the flight. Questionable flight regimes are sensed by the pilot as they are encountered, and previous flight experience in regions of close proximity gives him the capability of avoiding disastrous penetrations into these areas. A pilot can often recognize problems before they occur, evaluate problems as they occur, and take the best corrective action to accomplish the mission or recover the aircraft.

A pilot contributes more than his visual sense to the success of a mission. Pilots use senses such as hearing and touch to warn of impending trouble in turbines, engines, hydraulic and pressurization systems, instruments, and accessories. Aircraft have been saved because a pilot recognized the presence of an electrical fire, through smell, and took corrective action or returned for an emergency landing.

In research flying, the pilot is considered even more important to the success of a mission, since the very nature of research flying implies approaches and penetrations of unknown regions of flight. Unpredicted airplane motions have been encountered during these penetrations and, in most cases, some technique

of recovery has been used by the pilot which resulted in the recovery of the airplane. Examples of these unpredicted airplane motions are abrupt trim changes, pitch-up, roll-coupling, tumbling, dutch roll, aileron reversal, and directional divergence. Some of the recovery techniques used were not in keeping with standard procedure or doctrine, but were resorted to after other methods failed. Simple recovery techniques learned through experience, such as neutralizing controls, reducing velocity, or changing altitude, have enabled pilots to save many airplanes. Programing automatic control systems to effect nonstandard recoveries is possible only with excessive complexity, if at all.

Until each aircraft component that can affect the success of a mission can be considered 100-percent reliable, the pilot is a necessary complement to a flight control system. To achieve 100-percent reliability would entail excessive costs in design and component replacement.

The Flight Research Center is fully aware that some flight aborts occurred because of pilot error or malfunctions of pilot support systems such as oxygen or cabin pressurization systems; however, the FRC firmly believes that the advantages of using a human pilot as an integral component of a flight control system outweigh the disadvantages.

John Gibbons
Aeronautical Research Engineer

Milton O. Thompson
Aeronautical Research Pilot

Victor Horton
Aeronautical Research Engineer

TABLE I
ROCKET AND ROCKET-JET FLIGHT SUMMARY

ACFT	NASA	USAF	NAVY	USMC	DOUGLAS	BELL	NAA	TOTAL							
X-1 #1	0	49													
X-1 #2	50	1													
X-1 A	1	20				14									
X-1 B	15	8				4									
X-1 E	26	0													
X-2 #1	0	13													
D-558-II #143	1	0	19												
D-558-II #144	69	1	6	5											
D-558-II #145	39	2		5	7										
X-15 #670	6	0													
X-15 #671	0	0					2								
							9								
Total Flights	207	+	94	+	25	+	10	+	7	+	18	+	11	=	372
Total Flights Investigated	179	+	0	+	0	+	0	+	0	+	0	+	11	=	190
Total Incidents	81											+	3	=	84
% Incidents	45.3%												27.3%		
Serious Incidents	32											+	2	=	34
% Serious Incidents	17.9%												18.2%		
Minor Incidents	49												1		
Total Aircraft lost	1	①	2	②	0	0	0	2	④	0					
Aircraft Lost in Flight	0		1	③	0	0	0	1	⑤	0					
Pilots Lost	0		1	0	0	0	0	1		0					

*Definition of Serious and Minor Incidents for the purpose of this summary is defined on page 3.

- NOTES: 1 (X-1-A) Explosion in LOX tank of X-1A prior to drop, X-1A jettisoned
- 2 (X-1-D) Explosion in LOX tank of X-1D at low altitude during jettison prior to drop.
- 3 (X-2) Lost in flight after pilot separated escape capsule following extreme aircraft gyrations.
- 4 (X-1-3) Explosion in LOX tank of X-1-3 during LOX jettison on ground after aborted flight.
- 5 (X-2) Explosion in LOX tank of X-2 during systems check; airplane and pilot lost.

TABLE II
JET AIRCRAFT FLIGHT SUMMARY

Aircraft	Total Flights	Total Research	Total Incidents	Serious	Minor
F-100A #778	262	139	63	10	53
F-100C #717	53	13	27	8	19
F-104A #734	94	81	24	9	15
F-104A #749	81	70	9	3	6
F-104A #961	139	130	68	43	25
F-104B #303	30	20	16	10	6
F-107A #120	41	41	17	10	7
D-558-I #142	78	78	23	14	9
X-3 #892	24	24	10	3	7
X-4 #667	76	76	36	15	21
X-5 #838	122	122	43	26	17
TOTAL	1000	795	336	151	185
Total Flights Investigated		1000			
Total Incidents		336			
% Incidents		33.6%			
* Serious Incidents		151			
% Serious Incidents		15.1%			
Minor Incidents		185			
Total Aircraft Lost		1			
Total Pilots Lost		1			

*Definition of Serious and Minor incidents for the purpose of this paper is defined on page 3.

PILOT'S ROLE IN FLIGHT RESEARCH

The knowledge obtained from any research program is a direct function of the number of parameters measured. In any conceivable data-gathering system installed in a vehicle, there are some unrecorded parameters which can be qualitatively measured by the pilot. In addition, the pilot provides a means of expanding on, interpreting, or correlating the recorded information to give a more complete and meaningful report to the flight results. The argument that additional expense of money and weight are involved when a pilot is provided for is somewhat mitigated by the saving of money and time when a vehicle is recovered by pilot action. In the initial approach to a vehicle design in which a pilot is to be included, more effort is devoted to reliability and safety. This shows up in the later phases of the program in greater mission success as a result of concentrated effort to insure proper operation of a vehicle component or data system. Some vehicles have been designed to use automatic systems but have been modified to include a pilot monitor. This concept compromises both the automatic system and the pilot in many ways and both are penalized in unanticipated situations and control capability. The pilot is required to analyze the severity of an emergency and decide to override the automatic system without previous feel for the problem and without full knowledge of the manner in which the situation is deteriorating.

Inclusion of the pilot in the control loop at all times is desirable so that corrective action, when required, can be initiated by the pilot, using cues obtained during normal flight and early phases of a divergence, while the automatic portion of the system (similar to an airplane three-axis damper) is accomplishing the routine flight requirements.

Joseph Walker
Aeronautical Research Pilot

John B. McKay
Aeronautical Research Pilot

JW/JBMcK:fhs

Appendix H
Backup to DS-022-192

— DETAILED HISTORY —
REDUNDANT SYSTEMS AND PILOT-IN-THE-LOOP ASPECTS FOR ALL X-15 FREE FLIGHTS

20 September 1961

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Back-Up	No Pilot-In-The-Loop	
1-1-5	1. Pitch SAS malfunction prior to launch & design deficiencies, resulting in flight control oscillation just before landing.	1. Pilot made corrective control inputs.*	X P + R			X			Cancellation of X-15 launch if no manual direct control mode as backup to augmented mode.	Cancellation of X-15 launch, or probable loss of X-15 via crash on landing if SAS malfunction were not detected prior to launch.	
	2. Landing gear and structural damage.	2. No corrective action in flights.*							N/A	N/A	
2-1-3	1. Upper engine governor failure resulting in fuel pump rupture and fire.	1. No corrective action on flights*							N/A	N/A	
	2. Nose landing gear door damage.	2. No corrective action on flights*							N/A	N/A	

(*Post flight repair and redesign accomplished)

Effect Symbols Keys X —
0 —

Effect(s) of flight's most detrimental item(s).
Effect that would have been contributed by item had the flight not been affected by other more detrimental items.

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-in-the-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Backup	No Pilot-in-the-Loop	
2-2-6	1. SAS roll damper failed at launch.	1. Pilot attempted roll SAS reset to no avail—subsequently limited roll inputs.	X P + R		X P + R	X		X P + R P	Certain loss of X-15 if no manual direct control mode as backup to augmented mode. SAS monitor channel provided necessary fail-safety to prevent hard-over control signal.	Definite control ability problems and certain loss of X-15.	
2-3-9	1. Explosion in lower engine on start, resulting in fire and extensive damage in aft end of X-15.	1. Pilot shut down engines, jettisoned propellants and made emergency landing at alternate landing site.						X P X	N/A N/A	Loss of X-15. Pilot provided extreme flexibility commensurate with drastically altered flight requirements. Possible loss of X-15; pilot landed A/C under abnormal weight conditions and without roll damping.	
	2. Fuselage failure on landing—severe buckling aft of cockpit.	2. Repair and redesign subsequent to flight-failure due to structural deficiency and heavy, nose-high landing.									
	3. SAS roll damper failed at launch, and failed again in flight after reset.	3. Pilot attempted roll SAS reset to no avail—subsequently limited roll control inputs.	O P + R		O	O		O	Certain loss of X-15 if no manual direct control mode as back-up to augmented mode. SAS monitor channel provided necessary fail-safety to prevent hard-over control signal.	Definite control-ability problems and certain loss of X-15.	

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-in-the-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Backup	No Pilot-in-the-Loop	
1-2-7	1. Moderate stability and control problems due to failed SAS pitch damper.	1. Repeated pilot control inputs to dampen oscillations. SAS pitch failure not annunciated to pilot.	X		X	X		X	Certain loss of X-15 if no manual direct control mode as back-up to augmented mode.	Certain loss of control and resultant loss of X-15.	
2-4-1	1. Cooling system deficient prior to launch.	1. Pilot introduced ram air in lieu of continuing primary cooling system operation.	X		X*	X		X*	Probable equipment and passenger overheating. Cancellation of X-15 launch.	Possible equipment and passenger overheating. Cancellation of X-15 launch.	
	2. Hydraulic system #1 over-pressurized on start of APU #1 prior to launch.	2. Pilot monitored closely and allowed continued operation when #1 hydraulic pressures came back down to normal in 5 seconds.				X*		saved P and abort	N/A	Possible cancellation of X-15 launch via automatic or monitor cut-out.	
	3. Nose landing gear bottomed out because strut not fully pressurized prior to landing.	3. Repair and redesign subsequent to flight. No corrective action in flight.							N/A	N/A	

(*Pilot action saved on-board electronic gear from overheating; however, flight cancellation would have saved basic vehicle.)

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-in-the-Loop Effect			Result If	Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Backup	
2-5-12	1. Pitch and roll SAS failure on #1 APU start and pitch SAS failure at jettison check prior to launch.	1. Pilot reset SAS after cockpit instrument and ground monitor check in both instances.				O		P saved abort	N/A	X-15 launch would have been cancelled unless remote SAS reset capability were provided (pre-launch only).
	2. Primary launch mechanism failed.	2. Successfully used emergency launch system actuated by B-52 pilot.	P - R O			O		P saved abort	Cancelled X-15 launch and possible hazardous X-15 hang-up on B-52 pylon.	Cancelled X-15 launch and possible hazardous X-15 hang-up on B-52 pylon. (Note: B-52 pilot was in loop at this point.)
	3. Upper engine failed to start at launch due to inadequate prime.	3. Pilot reset controls, allowed time for adequate prime while gliding, and restarted engine.	P - R			O		O	Pump cavitation and failure, and explosive ignition (if no malfunction safe engine controls).	Certain loss of X-15 unless an additional control and guidance capability were included to effect altered flight profile and landing under nonnormal conditions.
	4. Upper engine automatic shut-down 220 sec. after launch. Lower engine continued to operate.	4. Pilot tried engine restarts to no avail, so immediately altered flight path drastically to avoid exceeding glide distance to landing site.					X	X	Unstable engine combustion and probable damage (if no malfunction safe engine controls).	Certain loss of X-15 unless an additional control and guidance capability were included to effect altered flight profile and landing under nonnormal conditions.
	5. Damage to L.H. landing gear bungee.	5. Repair subsequent to flight. No corrective action in flight.							N/A	N/A

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-in-the-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Backup	No Pilot-in-the-Loop	
2-6-13	1. SAS roll damper trip-out on high roll rates after launch.	1. Pilot reset roll dampers.	X		X	X		X P and abort	Certain loss of X-15. SAS roll monitor channel provided fail-safety to prevent hard-over control signal.	Loss of roll stability augmentation, resulting in certain loss of X-15.	
1-3-8	1. External B-52 power to X-15 radio failed prior to launch.	1. Pilot started #1 APU early to check radio on internal power—found problem.	O			O			Probable cancellation on X-15 launch due to inability to make check—emergency X-15 battery provided backup while APU #1 being turned on and loaded.	Probable cancellation of X-15 launch due to uncertainty of radio status.	
	2. SAS roll trip-out 2 min. before launch.	2. Pilot reset roll channel.				O			N/A	Cancelled X-15 launch unless remote SAS reset capability were provided (prelaunch only).	
	3. Upper engine failed to start at launch due to inadequate prime.	3. Pilot reset controls. Allowed time for reprime made one unsuccessful restart attempt, reset again and allowed more time for adequate reprime while gliding, and finally restarted engine.					X	X	Turbopump pump cavitation and failure, and explosive ignition (if no malfunction safe engine controls).	Certain loss of X-15 unless an additional control and guidance capability were included to effect altered flight profile and landing under nonnormal conditions.	

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-in-the-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Backup	No Pilot-in-the-Loop	
1-3-5 (Cont.)											
	4. Inertial guidance system was completely inoperative.	4. Air data system and alternate attitude indicator served as backups.	O			O		saved abort	Cancelled X-15 launch. On higher performance mission IGS is firm requirement.	Cancelled X-15 launch unless suitable backup auto or remote guidance system provided.	
	5. X-15 subsystems were not in spec. at planned launch point.	5. B-52/X-15 made 10 min. circle while pilot monitored cockpit gauges, recycled subsystems controls and assessed all systems ready for launch. Launch was accomplished at planned launch location on 2nd pass.				O			N/A	Cancelled X-15 launch.	
2-7-15	NONE	N/A							N/A	N/A	
2-8-16	NONE	N/A							N/A	N/A	
1-4-9	1. All SAS channels tripped out at B-52 to X-15 power transfer.	1. Pilot successfully reset all SAS channels.				X saved abort			N/A	Cancellation of X-15 launch unless remote SAS reset capability was provided (pre-launched only).	
	2. Hydraulic leak in #2 control line of lower rudder actuator.	2. Repaired subsequent to flight. #1 hydraulic system provided necessary redundancy. No correction in flight.	X						Possible loss of yaw control and subsequent loss of X-15.	None — pilot unaware of leak.	1/2
1-5-10	1. Hydraulic leak in #2 supply line of upper rudder actuator.	1. Repaired subsequent to flight. #1 hydraulic system provided necessary redundancy. No correction in flight.	X						Possible loss of yaw control and subsequent loss of X-15.	None — pilot unaware of leak.	1/2

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-in-the-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Backup	No Pilot-in-the-Loop	
1-6-11	1. All SAS channels tripped out when X-15 generators loaded before launch.	1. Pilot immediately reset all SAS channels.				X* avoid abort			N/A	X-15 launch would have been cancelled unless remote SAS reset capability were provided (prelaunch only).	
	2. SAS roll damper monitor channel failed at launch and on high roll inputs.	2. Pilot attempted to reset roll dampers in each case.				R			In this case redundancy effect of the fail-safe SAS roll monitor channel was a detriment, thus this failure would as the monitor channel (not the working channel) failed.	Fail-safe features required for pilot safety would not be operating for unpiloted flights; have been averted.	
	3. Lower ventral failed to jettison on primary jettison command.	3. Pilot lowered landing gear, which actuated an emergency jettison mechanism.	X		X				In this case X-15 would have landed with lower ventral attached, which means ventral would contact ground before landing gear, thus inflicting extensive damage to X-15.	N/A	
1-7-12	1. Inertial guidance system was completely inoperative.	1. Air data system and alternate attitude served as backup.	X			X			Cancelled X-15 launch. On higher performance flights IGS is firm req't.	Cancelled X-15 launch unless suitable backup auto or remote guidance system provided.	
	2. Radio communication with X-15 was intermittent and "hashy" on primary antenna.	2. Pilot switched to alternate antenna, and radio communication improved considerably.	X			avoid abort			Communication with pilot would have proved unacceptable and X-15 launch would have been cancelled.	N/A	

Detailed History — X-15 Free Flights (Cont'd)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Back-Up	No Pilot-In-The-Loop	
1-7-12 (cont.)	3. Homing indicator was inoperative.	3. Pilot headed X-15 on basis of ground radio calls regarding radar track.	X			X			Possible erroneous heading and loss of A/C.	Possible erroneous heading and loss of A/C unless alternate control system provided.	
1-8-13	1. All SAS channels tripped-out when X-15 generators were loaded before launch.	1. Pilot immediately reset all SAS channels.				X*			N/A	X-15 launch would have been cancelled unless remote SAS reset capability were provided (pre-launch only).	
	2. No ground-to-X-15 radio communication during most of ascending and early descending parts of flight.	2. Pilot had to rely upon airborne instruments and make necessary compensations.	X			X			No guidance information for pilot. X-15 would have been lost.	If inertial guidance system had been developed, a normal unpiloted flight could have been accomplished.	

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency Systems Effect			Pilot-In-The-Loop Effect			Result If No Redundant or Emergency Back-Up	No Pilot-In-The-Loop	Weighting Factor
			Completed Planned Miss.	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware			
2-9-18	1. Two reaction control rockets failed to shut off during prelaunch check when controls returned to neutral.	1. Pilot observed this and switched off the faulty reaction control system, leaving the other redundant system on.	X 1/2		Saved Abort	X 1/2			Had this been a high altitude flight, the flight would have been canceled or, if launch had occurred, insufficient control authority would have been available to the pilot at low q.	Cancellation of X-15 launch or if the failed open rocket had not been detected, APU & reaction control fuel would have probably been depleted before completion of the mission, resulting in loss of the X-15.	
	2. Severe SAS-induced control surface oscillations — one cycle just before landing & many cycles after landing.	2. Pilot stopped post-landing oscillations by turning SAS off.				X		X	N/A	Possible structural damage to X-15 after landing.	
1-9-17	1. LOX jettison valve failed to open after engine shutdown.	2. None. Engine shutdown on LOX exhaustion, so no significant LOX quantity left on board to jettison.							N/A	N/A	
1-10-19 (NONE)		N/A							N/A	N/A	

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	
1-11-21	1. LOX fill valve leaked during flight — called out by chase pilot.	None — chase pilot monitored leak until X-15 launch.							N/A
1-12-23	1. Inertial Guidance System had gross errors in altitude, total velocity and vertical velocity data both before and after launch.	1. Pilot used back-up sources of altitude and velocity data — namely, pressure instruments and ground radar call-out.	X			X			Cancellation of X-15 launch. Note: On higher performance X-15 flights inertial altitude and velocity data will be firm req't.
1-13-24	1. Complete engine failure at initiation of first turn after approximately 150 secs. of powered flight due to spurious power supply interruption.	1. Unsuccessful restart attempt. Pilot flew optimum glide return to base and performed successful landing.					X	X	N/A
1-14-27	1. Partial umbilical disconnect during B-52 takeoff causing: a) IGS to go into inertial mode. b) Failure of the B-52/X-15 intercom system.	a) Alternate sources of altitude and velocity data were used. (ground-radar, pressure instruments) b) X-15/B-52 communications performed on UHF radio.	X			X			Cancellation of X-15 launch. Cancellation of X-15 launch.
									Assuming that the IGS would provide guidance information directly to the control system for the un-piloted case, the launch would have been cancelled. Certain loss of X-15 unless an additional control and guidance capability were included to effect altered flight profile and landing under non-normal conditions. Cancellation of X-15 launch. (Refer to flt. 1-12-23)
									N/A

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem Or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Result If	No Pilot-In-The-Loop	Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware			
1-15-28	(NONE)	N/A							N/A	N/A	
1-16-29	(NONE)	N/A							N/A	N/A	
2-10-21	1. LN ₂ supply valve for cockpit pressurization and equipment cooling froze shut prior to launch.	1. Pilot called for hold at 7 min. before planned launch. Pilot changed cooling modes to subject valve to warm air and thaw it. Valve thawed and launch occurred 20 min. later on 3rd pass over planned launch location.	X			X			Cancellation of X-15 launch. (Alternate cooling mode and flexibility of pilot control over pressurization and cooling system provided necessary emergency back-up to primary mode.)	Cancellation of X-15 launch.	
	2. X-15 and B-52 intercom failed.	2. X-15 and B-52 crew continued flt. by communicating via UHF.	X						Cancellation of X-15 launch.	N/A	
1-17-30	1. Lower engine shut-down during first turn after approximately 155 secs. of powered flight due to spurious power supply interruptions.	1. Pilot reset lower engine circuit breaker and performed successful re-start of the engine.				X		X	N/A	Inability to reset circuit breaker and re-start engine would have resulted in certain loss of X-15 unless an additional control and guidance capability were included to effect altered flight profile and landing under non-normal conditions.	

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Non Redundancy of Emergency Back-Up	No Pilot-In-The-Loop	
2-11-22	1. One reaction control rocket exhausted raw fuel and would not shut completely off when controls returned to neutral.	1. Pilot observed this and switched off the faulty reaction control system, leaving the other (redundant) system on.	X			X			Had this been a high altitude flight, the flight would have been canceled without the reaction controls redundancy, or had launch occurred, insufficient low q control would have resulted.	Concancellation of X-15 launch or, if leak not detected and launch had been made, APU and reaction control fuel may have been depleted, resulting in loss of the X-15.	1/2
1-18-31	1. One engine chamber could not be ignited.	1. Alternate flight profile was flown with 7 chambers operating.					X		N/A	Possible loss of X-15 due to instability to accomplish the alternate mission with an unpowered system.	

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Result If Emergency Back-Up	No Pilot-In-The-Loop	Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware			
2-12-23	1. An automatic malfunction shut-down of the (XLR99) engine occurred on the first of 2 planned manual shutdown restart cycles.	1. Pilot recycled engine controls, reprimed and obtained satisfactory engine restart on 2nd attempt. In this process pilot made considerable alteration to planned flight profile.					X	X	Hazardous XLR99 engine occurrence. (Auto malfunction shutdown system protected against undetermined hazardous condition in start sequence).	Certain loss of X-15 unless an additional control and guidance capability were included to effect altered flight profile and landing under non-normal conditions.	
	2. One reaction control rocket stuck open after postlaunch actuation when controls returned to neutral.	2. Pilot made quick test of reaction controls to check A/C reaction response and then shutoff both systems to prevent loss of fuel.		X		O			N/A	Depletion or partial depletion of reaction control and APU fuel due to nondetection of leak and no corrective capability without pilot. Possible loss of the X-15 would have resulted.	1/2
1-19-32	None	N/A							N/A	N/A	
1-20-35	None	N/A							N/A	N/A	
1-21-36	None	N/A							N/A	N/A	
2-13-26	None	N/A							N/A	N/A	

Appendix H
Backup to DS-022-192

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Back-Up	No Pilot-In-The-Loop	
2-14-28	1. Engine shut-down on first start attempt due to intermittent fire switch.	1. Pilot reset engine reprimed, restarted engine and made minor necessary alterations to the flight plan to reach intended flight goals.				X		X	N/A	Certain loss of X-15 unless an additional control and guidance capability is included to effect altered flight profile and landing under non-normal conditions and at remote location.	
	2. Cockpit pressurization and cooling malfunction prior to launch.	2. Pilot recycled controls several times and successfully cleared the problem prior to launch.				X			N/A	Probable cancelled launch due to inability to cycle heat and vent controls and correct problem.	
	3. Structural vibration encountered during re-entry — sustained by SAS.	3. Pilot reduced pitch and yaw damper gains causing vibration to stop after approximately 30 seconds.				X		X	N/A	Inability to lower gain settings would have resulted in sustained continuous vibration throughout remainder of flight and probable major structural damage and loss of X-15.	

Appendix H
Backup to DS-022-192

Detailed History —X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Back-Up	No Pilot-In-The-Loop	
2-14-28 (Cont.)	4. Stopwatch in cockpit reading 4 seconds ahead of actual burning time.	4. Pilot recognized difference between prime and backup timing, analyzed situation to determine which was correct, and shutdown engine on ground time callout.	X						Early engine shutdown would have resulted in less performance than expected resulting in an alternate mission profile.	N/A	
2-15-29	1. Auto malfunction shutdown of the XLR99 engine immediately following launch.	1. Pilot reset engine controls, reprimed engine system while gliding, accomplished successful engine restart, and made necessary control inputs to arrive at same powered flight profile and points as planned.	X		X	X		X	Hazardous XLR99 engine occurrence. (Auto malfunction shutdown system protected against undetermined hazardous condition in start sequence).	Certain loss of X-15 unless additional control and guidance capability were included to effect altered flight profile and landing under non-normal conditions and at remote location.	
	2. SAS pitch channel tripped out at final engine shutdown to failure in the SAS pitch gain selector switch.	2. Pilot reset SAS pitch channel after quickly assessing system status.	X		X	X		X	Certain loss of X-15 if no manual direct control made as backup to augmented mode. SAS monitor channel provided necessary fail-safety to prevent hard-over control signal.	Definite controllability problems and certain loss of the X-15.	

Appendix H
Backup to DS-022-192

Detailed History —X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Backup	No Pilot-In-The-Loop	
2-15-29 (Cont.)	3. Partial cabin pressurization failure one minute after engine shutdown.	3. Pilot's pressure suit inflated and maintained proper pilot environment.	X saved pilot		X				The pilot's pressure suit provided necessary emergency backup without which pilot would have been incapacitated and X-15 lost.	N/A	
	4. Inertial altitude data was grossly in error.	4. Pilot referenced other forms of flight data — namely ground radar call-out, pressure instruments (air data system), and other flight parameters from inertial data.	X			X			Canceled X-15 launch. On higher performance mission good IGS data is firm req't.	Canceled X-15 launch unless suitable backup auto or remote guidance system provided.	
	5. Stopwatch in cockpit read 9 sec. ahead of actual burning time.	Pilot recognized difference between prime and backup timing, analyzed situation to determine which was correct, and shut down engine on ground time callout.	X						Early engine shutdown would have resulted in less performance than expected, thus resulting in an alternate mission profile.	N/A	

Appendix H
Backup to DS-022-192

Detailed History —X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Back-Up	No Pilot-In-The-Loop	
2-16-31	1. Pitch-roll SAS malfunction at launch.	1. Roll damper reset, pitch damper could not be reset.	X		X	X		X	Certain loss of X-15 if no manual direct control mode as backup to augmented mode. SAS monitor channel provided fail-safety to prevent hard-over control signal.	Definite control-lability problems and certain loss of X-15.	
	2. Stop watch in cockpit failed to operate.	2. Pilot used ground time callouts to accomplish desired flight profile.	X						A less accurate flight profile would have resulted if time backup were not provided and IGS or radar values were used.	N/A	
	3. Partial cabin pressurization failure after engine shutdown.	3. Pilots pressure suit inflated and maintained proper pilot environment.	X		X				Certain loss of X-15 due to incapacitation of pilot exposed to adverse environment.	N/A, except incapacitation of passenger, if any.	
2-17-33	1. Partial cabin pressurization failure during powered X-15 climb.	1. Pilots pressure suit inflated and maintained proper pilot environment.	X		X				Certain loss of X-15 due to incapacitation of pilot exposed to adverse environment.	N/A, except incapacitation of passenger, if any.	

Appendix H
Backup to DS-022-192

Detailed History — X-15 Free Flights (Cont.)

Flight No.	Type Problem or Failure	Corrective Action	Redundant or Emergency System Effect			Pilot-In-The-Loop Effect			Result If		Weighting Factor
			Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	Completed Planned Mission	Alter-nate Miss.	Saved Hard-ware	No Redundancy or Emergency Back-Up	No Pilot-In-The-Loop	
1-22-37	1. X-15 launch switch malfunction.	1. Launch occurred after pilot recycled switch several times.							N/A	N/A (B-52 back-up launch provisions would have been reverted to).	
	2. Partial cabin pressurization failure after engine shutdown.	2. Pilot's pressure suit inflated and maintained proper pilot environment.	X		X				Certain loss of X-15 due to incapacitation of pilot exposed to adverse environment.	N/A except incapacitation of passenger, if any.	
2-18-34	1. APU #2 became inoperative at 1.5 min. before rescheduled launch due to an apparent control or valve intermittency.	1. Pilot made successful APU restart and reloaded #2 generators in time to continue with launch only 1 min. behind schedule.	O			O	1/2		Probable cancellation of X-15 launch without APU redundancy B-52 power would have been required before single APU restart could have been attempted. Planned launch point would have been exceeded, and successful launch on 2nd pass would be very marginal.	Cancellations of X-15 launch. APU could not be restarted nor generator reloaded remotely. X-15, unpiloted or not, would not be launched without benefit of capacity of both APU's as required to complete a full-blown mission.	1/2

Appendix H
Backup to DS-022-192

Detailed History — X-15 Free Flights (Cont.)

<u>Flight No.</u>	<u>Type Problem or Failure</u>	<u>Corrective Action</u>	<u>Redundant or Emergency System Effect</u>			<u>Pilot-In-The-Loop Effect</u>			<u>Result If</u>		<u>Weighting Factor</u>
			<u>Completed Planned Mission</u>	<u>Alter-nate Miss.</u>	<u>Saved Hard-ware</u>	<u>Completed Planned Mission</u>	<u>Alter-nate Miss.</u>	<u>Saved Hard-ware</u>	<u>No Redundancy or Emergency Back-Up</u>	<u>No Pilot-In-The-Loop</u>	
2-18-34 (Cont.)	2. Engine fuel inlet pressure dropped below minimum operating limit, as indicated by warning light and cockpit fuel line pressure gauge.	2. Pilot throttled engine back from 100% to 50% thrust to decrease pressure drop in the fuel feed line. The engine fuel inlet pressure rose to acceptable operating value. Pilot eased throttle up to 75% thrust and observed no decay in fuel inlet pressure. Pilot then made necessary alterations to the flight plan to approach same powered flight profile goals as planned.		X	X		X	X	Malfunction detection and warning function of engine low fuel inlet pressure light/gage prevented probable loss of X-15 due to in-flight fire/explosion or premature engine shutdown upon chamber burn-through.	Probable loss of X-15 due to in-flight fire/explosion upon chamber burn-through or due to premature engine shutdown upon malfunction detection or chamber burn-through, unless an additional control and guidance capability were included to effect altered flight profile and landing under non-normal conditions at a remote location.	

Appendix I
Backup to DS-022-198

Cost for Automation	SYSTEM	TOTAL FLIGHTS	WITHOUT PILOT				WITH PILOT								LOST MISSIONS SAVED BY PILOT	LOST ACFT. SAVED BY PILOT	DYNA-SOAR FLIGHTS REQUIRED TO COMPLETE 18 MISSIONS			
			SUCCESS		ACFT. LOST		SUCCESS		ALT. MISSION		TOTAL		ACFT. LOST				CASE I		CASE II	
			No. F suc	R suc	No. F suc	%	No.	%	No.	%	No.	%	No.	%			%	%	Pilot	No Pilot
200.2	X-15	40	22	55	16	40	33	83	6		39	97.5	0	0	95	100	18.5	31	21.6	37
262.0	Bomarc	167	85	51	82	49	137	82	19		156	93.5	11	6.6	87	87	19.2	35	22.6	43
354.0	Bomarc	60	26	43	34	57	51	85	7		58	96.5	2	3.3	94	94	18.7	41	22	51
	Minuteman	4	1	25	3	75	3	75	1		4	100	0	0	100	100				
139.0	Mercury	6	4	66							5	83			50		21.6	27		
62.0	Regulus*	784	632	81	152	19	676				676	86	108	14	29	29	21.0	22		
	F8U	32,761											32	.1						
139.0	Jet Aircraft	1,000	664	66	151	15							1	.1		99.5		27		
185.0	Rocket Acft.		116/190	61	34/190	18							2/372	.5		89		30		
	Regulus (1st flights) *	100	85	85	15	15	94	94			94	94	6	6	60	60	19.2	21.2		
	Regulus (1st flights) **	100	859	85	15	15	98	98			98	98	2	2	87	87	18.4	21.2		

For X-15 $R_{suc} = \frac{F_{suc}}{40}$. Additional Flights Required for Automation. Additional $F_{suc} = \frac{18}{F_{suc}}$
 $R = .83$ Without Pilot
 $.85$ With Pilot

* Pilot only — No Additional Redundancy or Backup Provided
 ** Pilot Plus Redundancy

Case I — Assume Data is comparable to Dyna-Soar Air Vehicle

Case II — Assume Data is comparable to Dyna-Soar Glider. Booster